



Acquisition Directorate

Research & Development Center

Report No. CG-D-03-14

Domestic Ice Breaking (DOMICE) Simulation Model User Guide

Distribution Statement A: Approved for public release; distribution is unlimited.

February 2013



Homeland
Security

NOTICE

This document is disseminated under the sponsorship of the Department of Homeland Security in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

This report does not constitute a standard, specification, or regulation.



Mr. Timothy Hughes
ASA Branch Chief
United States Coast Guard
Research & Development Center
1 Chelsea Street
New London, CT 06320



1. Report No. CG-D-3-14		2. Government Accession Number		3. Recipient's Catalog No.	
4. Title and Subtitle Domestic Ice Breaking (DOMICE) Simulation Model User Guide				5. Report Date February 2013	
				6. Performing Organization Code Project No. 7519	
7. Author(s) Mark Krempley, Anthony Barrett, Sarah Marlay, Mark VanHaverbeke				8. Performing Report No. RDC UDI #1359	
9. Performing Organization Name and Address ABS Consulting, Inc., 1 Chelsea Street New London, CT 06320		U.S. Coast Guard Research and Development Center 1 Chelsea Street New London, CT 06320		10. Work Unit No. (TRAIS)	
				11. Contract or Grant No. HSCG32-08-D-R00007/ T.O. HSCG32-11-J-20085	
12. Sponsoring Organization Name and Address U.S. Department of Homeland Security Commander (LANT-73) U.S. Coast Guard Atlantic Area 431 Crawford St. Portsmouth, VA 23704-5004				13. Type of Report & Period Covered Final	
				14. Sponsoring Agency Code Atlantic Area (LANT-73) Portsmouth, VA 2704	
15. Supplementary Notes The R&D Center's technical point of contact is Mark VanHaverbeke, Phone: 860-271-2754, email: Mark.G.VanHaverbeke@uscg.mil					
16. Abstract (MAXIMUM 200 WORDS) The Domestic Ice Breaking (DOMICE) Simulation Model was developed to update the Operational Risk Assessment Model (ORAM) and add additional rigor to its analysis capabilities related to the United States Coast Guard (USCG) DOMICE mission. Additionally, the DOMICE Simulation Model provides a more complete assessment of risk associated with ice breaking activities by analyzing the various levels of impacts incurred from unmet ice breaking demand. This document, the DOMICE Model User Guide, provides information to advanced users of the DOMICE Simulation Model in the software Analytica®. The User Guide is intended to provide a technical and detailed description of the model as an addendum to the "Domestic Ice Breaking (DOMICE) Technical Report on DOMICE Simulation Model." The "Technical Report" should be utilized as a more general overview of the DOMICE Simulation Model. This User Guide aims to explain processes related to regular uses of the model, including setting up the model for routine analyses, running the computational model, and interpreting the model's results. Additionally, this document provides instructions for more advanced uses, which include updating the model's data on an annual basis and changing model settings to reflect more fundamental changes in model assumptions. This document was updated in January 2013 to include enhancements and adjustments made to improve the ORAM Model.					
17. Key Words Icebreaking, U.S. Coast Guard, modeling, simulation, service life extension program, WLB, WLM, WTGB, WYTL, WLBB, DOMICE		18. Distribution Statement Distribution Statement A: Approved for public release; distribution is unlimited.			
19. Security Class (This Report) UNCLAS//Public		20. Security Class (This Page) UNCLAS//Public		21. No of Pages 102	
				22. Price	



(This Page Intentionally Left Blank)



TABLE OF CONTENTS

LIST OF FIGURES	vii
LIST OF TABLES	viii
LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLs	ix
1 Overview	1
2 Key Changes in Version 2.0	2
2.1 Variable Changes and Additions.....	3
3 Basic User Interface.....	4
3.1 Basic User Inputs	5
3.2 Basic User Outputs.....	6
3.3 Technical Specifications and Requirements	7
4 Comprehensive Tour and Screenshots of the Model’s Modules.....	8
4.1 Model Variables	8
4.2 Ice Breaking Demand Module	10
4.2.1 Waterway Ice Characteristics and Ice Data Sub-Module	10
4.2.2 Waterway Criticality Sub-Module.....	17
4.3 Ice Breaking Supply Module.....	18
4.3.1 Inventory of Icebreakers Sub-Module	19
4.3.2 Characteristics of Icebreakers Sub-Module	19
4.3.3 Other Missions and Maintenance of Icebreakers Sub-Module.....	21
4.3.4 Assignment of Icebreakers to Waterways Sub-Module.....	22
4.4 Economic Impact Module	35
4.4.1 Cargo Flow.....	36
4.4.2 Calculation of Economic Impact of Waterway Closure	39
4.5 DOMICE Outcomes.....	46
4.6 Model Sensitivity	48
5 Detailed Model Overview and Description of Variables	49
5.1 Ice Breaking Demand.....	50
5.1.1 Waterway Ice Characteristics and Ice Data	50
5.1.2 Waterway Criticality and Vessel Traffic	54
5.2 Ice Breaking Supply	54
5.2.1 Inventory of Icebreakers	54
5.2.2 Characteristics of Icebreakers	55
5.2.3 Probability of Ice Breaking Asset Being Unavailable	56
5.2.4 Assignment of Icebreakers to Waterways.....	57

TABLE OF CONTENTS (Continued)

5.3	Waterway Closure Economic Impact.....	60
5.3.1	Cargo Volumes	61
5.3.2	Vessel Volume, Value, and Number.....	62
5.3.3	Cargo and Home Heating Oil Impact	63
5.3.4	Flooding Impact	64
5.4	DOMICE Outcomes	65
6	Update Frequency of Model Variables and Known Issues.....	66
6.1	Update Frequency	66
6.2	Known Issues	68
7	Data Analysis and Storage	69
7.1	Overview of Data Analysis and Storage	69
7.2	General System Requirements	69
7.2.1	Sufficient Computing Power.....	70
7.2.2	PHP / MySQL Environment	70
7.2.3	Access to Port 80 / Webserver	70
7.3	Data Configuration.....	70
7.4	AIS Data Processing.....	72
7.4.1	Overview of AIS Data	72
7.4.2	Obtaining AIS Data.....	73
7.4.3	Step 1: Database Setup.....	74
7.4.4	Step 2: Input and Scrub.....	76
7.4.5	7.4.5 Step 3: Run Processing Scripts	78
7.4.6	Step 4: Format Output for <i>Analytica</i> ®.....	78
7.5	Ice Data Processing	79
7.5.1	Overview of Ice Data	79
7.5.2	Obtaining Ice Data	80
7.5.3	Step 1: Database Setup.....	81
7.5.4	Step 2: Input and Scrub.....	82
7.5.5	Step 3: Run Processing Scripts	83
7.5.6	Step 4: Format Output for <i>Analytica</i> ®.....	83
7.6	Meteorological Data Processing.....	85
7.6.1	Overview of Meteorological Data	85
7.6.2	Obtaining Meteorological Data.....	85
7.6.3	Step 1: Database Setup.....	86
7.6.4	Step 2: Input and Scrub.....	90
7.6.5	Step 3: Run Processing Scripts	91
7.6.6	Step 4: Format Output for <i>Analytica</i> ®.....	91



LIST OF FIGURES

Figure 1. High-level view of DOMICE Analytica® model.	2
Figure 2. Basic user interface.....	5
Figure 3. Overview of the DOMICE model.	8
Figure 4. Model variables.	9
Figure 5. Ice breaking demand module.....	10
Figure 6. Waterway ice characteristics and ice data sub-module.	11
Figure 7. Waterway geography sub-module.....	12
Figure 8. Ability to select shortened waterway lengths in D1 sub-module.	12
Figure 9. Historical and sampled ice data sub-module.	13
Figure 10. District 9 historical ice data sub-module.	14
Figure 11. Sampled District 1 air temperatures sub-module.	15
Figure 12. District 1 packed brash ice regression model and residual sampling sub-module.	16
Figure 13. District 1 plate ice regression model and residual sampling sub-module.	16
Figure 14. District 1 and 9 ice model combinations and exceptions sub-module.	16
Figure 15. Selection of ice/weather data year sub-module.	17
Figure 16. Waterway criticality sub-module.	18
Figure 17. Ice breaking supply module.....	18
Figure 18. Inventory of icebreakers sub-module.	19
Figure 19. Characteristics of icebreakers sub-module.	20
Figure 20. Transit time sub-module.....	21
Figure 21. Other missions and maintenance of icebreakers sub-module.....	22
Figure 22. Assignment of icebreakers to waterways sub-module.	23
Figure 23. Whether ice breaking is needed in a waterway and an ice breaker in its District can break it sub-module.	24
Figure 24. Inventories and availabilities of icebreakers sub-module.	25
Figure 25. Sequential ice breaker assignments sub-module.	26
Figure 26. Assignment of available 240s to maintain any tracks where track maintenance was being performed the previous day sub-module.	28
Figure 27. Assignment of available 65s to maintain any tracks where track maintenance was being performed the previous day.	28
Figure 28. Assignment of any 175s to clear tracks.....	29
Figure 29. Assignment of icebreakers to any advance assignments sub-module.	30
Figure 30. SAR standby duty requirements sub-module.	31
Figure 31. Tables for time- and weather-dependent rules on types of ice breaking sub-module.	32
Figure 32. Waterway priority for asset assignment sub-module.	33
Figure 33. Other factors considered during ice breaker assignment sub-module.....	34
Figure 34. Outputs of assignment process.	35
Figure 35. DOMICE economic impact module.....	36
Figure 36. Vessel number sub-module.	37
Figure 37. Vessel number sub-module.	38
Figure 38. District 1 cargo flows sub-module.	39
Figure 39. Waterway volume and value sub-module.	40
Figure 40. Total waterway value.	40



LIST OF FIGURES (Continued)

Figure 41. Impeded vessels, value, and volume sub-module.	41
Figure 42. Cumulative volume impeded sub-module.	41
Figure 43. Cargo and home heating oil impact sub-module.	42
Figure 44. Operating costs sub-module.	43
Figure 45. Alternative shipping impact sub-module.	43
Figure 46. Downstream impacts sub-module.	44
Figure 47. Disaggregated cargo results sub-module.	44
Figure 48. Flooding impact sub-module.	45
Figure 49. Flooding impact by waterway sub-module.	45
Figure 50. DOMICE outcomes.	46
Figure 51. Calculations of hours of unused icebreaker availability.	47
Figure 52. Model sensitivity.	48
Figure 53. Sample file indicating the central GPS points and surrounding geographical “boxes” for critical waterways.	74
Figure 54. Screen snapshot of a portion of the Great Lakes waterway grid system, located in the “boxmap.htm” file.	80

LIST OF TABLES

Table 1. Database waterway numbering scheme.	84
Table 2. Critical waterways in District 1.	86

LIST OF ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AIS	Automatic Identification System
ATON	Aids to Navigation
CGD	Coast Guard District
COTS	commercially available off-the-shelf
D1	USCG District One (northeast)
D9	USCG District Nine (Great Lakes)
DOMICE	domestic ice breaking
dpw-2	USCG District Nine Waterways Management Branch
GPS	Global Positioning System
HHO	home heating oil
LCA	Lake Carriers' Association
MAR	USCG Domestic Icebreaking Mission Analysis Report, released in May 2010
NCDC	National Climactic Data Center
NIC	National Ice Center
NOAA	National Oceanic and Atmospheric Administration
ORAM	Operational Risk Assessment Model
PWCS	Ports, Waterways and Coastal Security
RIN	Risk Index Number
SAR	Search and Rescue
SIGRID	Sea Ice Grid
SLEP	Service Life Extension Program
SME	Subject Matter Expert
USACE	United States Army Corps of Engineers
USCG	United States Coast Guard
WCSC	Waterborne Commerce Statistics Center
WLB	225-foot ice capable buoy tender
WLBB	240-foot heavy icebreaker
WLM	175-foot ice capable buoy tender
WMO	World Meteorological Organization
WTGB	140-foot medium ice breaking tug
WYTL	65-foot light ice breaking harbor tug



(This Page Intentionally Left Blank)



1 OVERVIEW

The Domestic Ice Breaking (DOMICE) Simulation Model was developed to update the United States Coast Guard's (USCG) Operational Risk Assessment Model (ORAM) and add additional rigor to its risk analysis capabilities related to the USCG DOMICE mission. In the face of an aging domestic icebreaker fleet, there is a growing need to more fully assess the implications of Service Life Extension Programs (SLEP) and unscheduled maintenance in order to mitigate potential consequences of maintenance-related reductions in ice breaking capabilities. There is also a need to examine further the risk associated with a number of varying conditions that significantly affect DOMICE operations, such as varying levels of winter severity and differences in waterway characteristics. The DOMICE Simulation Model is a tool for the USCG to quantify the risk associated with different ice breaking asset allocation decisions and varying conditions in both operational and natural environments. Additionally, the DOMICE Simulation Model provides a more complete assessment of risk associated with ice breaking activities by analyzing the various levels of impacts incurred from unmet ice breaking demand. The DOMICE Simulation Model allows ORAM to quantify risk with unprecedented levels of detail in order to improve icebreaker deployment strategies in USCG Districts 1 and 9.

This document, the DOMICE Model User Guide, provides information to advanced users of the DOMICE Simulation Model in the software *Analytica*®. The User Guide is intended to provide a technical and detailed description of the model as an addendum to the “Domestic Ice Breaking (DOMICE) Technical Report on DOMICE Simulation Model.” The “Technical Report” should be utilized as a more general overview of the DOMICE Simulation Model. This User Guide aims to explain processes related to regular uses of the model, including setting up the model for routine analyses, running the computational model, and interpreting the model's results. Additionally, this document provides instructions for more advanced uses, which include updating the model's data on an annual basis and changing model settings to reflect more fundamental changes in model assumptions.

Section 2 of the User Guide describes the user interfaces for both basic and advanced users of the model. Next, Section 3 provides a comprehensive tour of the model's modules, including screenshots and descriptions of each module. Section 4 provides additional detail for advanced users on how to change the model's input variables and data sets. This section focuses on specific, key computational model variables within each of the model's main modules. Generally, the following information is provided for each variable: the name or title of the variable; a brief description of the variable; the variable's units of measure; how to edit or update data; and key dependencies between the variable and other variables. Section 5 consists of a summarized list of key model variables for both regular and advanced uses of the model. Finally, Section 6 provides a detailed explanation of the processes and steps necessary to update existing data in the model.

Throughout the User Guide, descriptions of the model's modules and sub-modules generally follow in order of the computational model's hierarchical modules. Figure 1 below shows the basic structure of the model and how the model integrates the following three main modules: the “Ice Breaking Demand” module; the “Ice Breaking Supply” module; and the “DOMICE Economic Impact” module. Many or all of the variables discussed in this User Guide can be accessed or changed through these three main modules displayed in Figure 1 and found in the “Model Details and Algorithms” node. It is important to note, however, that these values can also be accessed or changed by means of either the basic user interface displayed when the user first opens the model, or within the advanced user interface.

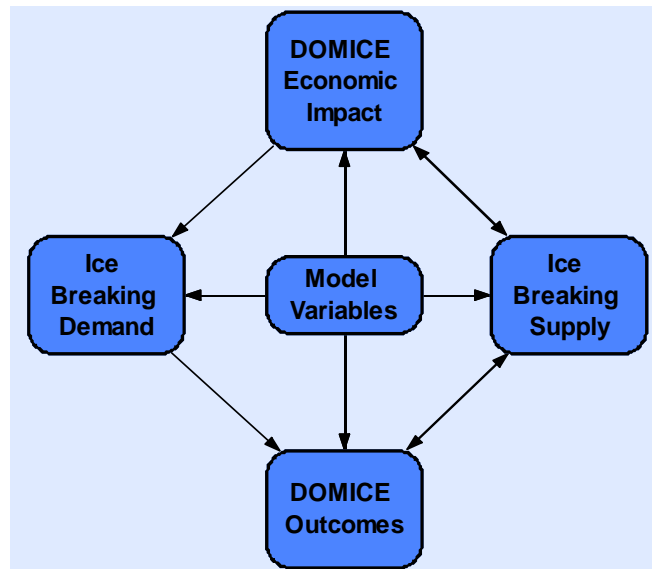


Figure 1. High-level view of DOMICE Analytica® model.

2 KEY CHANGES IN VERSION 2.0

Version 2.0 of the DOMICE ORAM Simulation Model was developed in late 2012 in order to improve the assignment of icebreakers, reduce the model's time step, and address a number of additional features and improvements that were identified in version 1.0.

This update required a number of changes to existing model parameters to enable the revised calculations, and included a number of small adjustments to improve the accuracy of individual model parameters, such as asset capability. Significant revisions to model functionality include:

- **More granular time-step:** Version 2.0 simulates the whole ice-season on a day-by-day basis rather than a weekly basis
- **Assignment of Icebreakers:** Version 2.0 supports static and dynamic assignment of multiple assets to a particular waterway
- **Additional Asset Class:** The two Canadian icebreakers are now differentiated into two classes.
- **Improved Transit Time Calculations:** Version 2.0 calculates transit time explicitly based on assignment of assets on the previous day
- **Greater User Control of Assignments:** Version 2.0 includes additional features that enable enhanced user control of icebreaker assignment, including explicit prioritization of waterways
- **Model Parameter Refinement:** Multiple model parameters were refined and updated including icebreaker capability and waterway length
- **In Model Comparison:** Users can simultaneously evaluate two different asset deployment scenarios and view the different results in a single model run

Details on the impact of individual sub-modules and variables are documented throughout the user guide and the model itself. (Changes to this guide are indicated by a vertical line in the right-hand margin.)

2.1 Variable Changes and Additions

In order to introduce the model improvements in version 2.0, a number of additional variables were added, and the definitions to others were made. New variables and key changes to existing variables added are noted below. Key variables are further defined in Section 5.

- **Time** (Time): The model time step is now defined as a sequence of 0 to 140 reflecting all the days in the ice season. It is important to note that, unless a conversion is done, all data must now be entered on a **DAILY** basis.
- **Day to Week** (Day_to_Week): This table aligns the days in the new time step with the weeks from the previous time step. This variable is used to convert existing weekly data (e.g., ice conditions) to daily data. No maintenance or updating is required for this variable. A number of variables in the ice conditions sub-module utilize this variable. No maintenance or regular updating to those variables, which simply serve as “pass-through” conversions, is necessary.
 - The standard syntax to convert weekly data to daily data is: (AGGREGATE(1, Day_to_Week, Time, Week); (*Variable with Weekly Data* [Time = Week]) [Week=Day_to_Week])
 - Data can be distributed evenly (e.g., dividing a weekly sum over seven days, by applying the following function: (AGGREGATE(1, Day_to_Week, Time, Week); (*Variable with Weekly Data*/7 [Time = Week]) [Week=Day_to_Week])
 - Data calculated on a daily basis can be summed on a weekly basis using the following syntax: Aggregate(*Daily Data*, day_to_Week, time, week)
- **Allocation Alternatives** (Allocation_Alternati): This variable defines the two in model variations used to compare alternative allocations of icebreakers. No maintenance or regular updating is required for this variable.
- **Ability to select shortened waterway lengths in D1:** This submodule contains the different lengths, and ability to select the different lengths, of four waterways in District 1: the Hudson River System, the Manhattan River System, the Cape Cod Canal, and the Connecticut River. The user can directly select which waterway length to use from the Advanced User Controls menu. No maintenance or regular updating is required for this variable.
- **Asset Classification** (Asset_classification): The two classes of Canadian icebreaking assets (1050/Samuel Risley, 1100/Griffon) now appear as separate asset classes in the model.
 - **Ice Breaking Capacities *** (Ice_breaking_capacit): This variable contains revised capabilities for the Canadian Assets, and can be updated if additional information is available from the CCGS.



- **Waterway to Waterway Distance** (Waterway_to_Waterway): This table records the distance (in miles) between all the waterways within a given district. It is used in calculating transit time. No regular maintenance or updating of this variable is necessary.
- **Asset Transit Speed** (Asset_Transit_Speed): This table contains the speed at which different classes of assets can transit between waterways. This variable should be confirmed with SMEs on an annual basis.
- **Number of Passes Needed Per Day** (Number_of_passes_nee): This variable replaces the previous input of passes required per week, and has been updated based on SME input. This variable should be confirmed with SMEs on a regular basis.
- **Locations where particular classes of assets will never be deployed** (Locations_where_part): This variable was created to give the user greater control over asset deployment locations and allows the user to specify locations where an asset will never be deployed. It was populated with data based on SME input, and should be confirmed with SMEs on a regular basis.
- **Waterway Importance by Asset Class** (Waterway_Importance1): This variable allows user to add a manual weighting factor to each waterway/asset class pairing and is used in prioritizing waterways for clearing/maintenance. It was developed with SME input and calibrated to generate results that best aligned with SME expectations of deployments. It can be accessed from the Advanced User Control menu and can be regularly updated to generate refined results or conduct “what-if” analysis.
 - **Waterway Importance Levels** (Waterway_Importance_): This variable contains the different levels of priority that can be assigned to each waterway
 - **Priority Conversion** (Priority_Conversion): This variable shows the conversion of importance levels to mathematical values
- **Advance assignments of icebreakers** (Advance_assignments): This variable has been substantially updated based on SME input on the type of assignments known in advance.

3 BASIC USER INTERFACE

The *Analytica*® model includes user interfaces intended to provide both basic and advanced users of the model with convenient access to the main model inputs and outputs. The input and output buttons of the basic user interface are tools to interact with the relevant model variables without requiring the user to locate variables in the hierarchy of nested influence diagrams that graphically comprise the model’s modules, which will be explored in detail in Section 3.

This section discusses basic model set up and execution, including setting up the model for routine analyses, running the computational model, and interpreting the model’s results. Figure 2 shows the basic user interface, which appears when the *Analytica*® model file is first opened. The basic user interface includes both inputs and outputs for use in the most routine analyses.

DOMICE
v2.0

Basic User Inputs

Baseline Inventory of Icebreakers ** [Edit Table](#)

Mid-Season Weekly Icebreaker Inventory Adjustments [Edit Table](#)

User Choice of Specified or Randomly Selected Ice and Weather Data Years [Random Years](#) ▼

User Choice of Ice and Weather Data Years, if Applicable [All](#) ▼

Basic Model Outputs

Adjusted Inventory of Icebreakers ** [Calc](#) mid

Outputs of assignment process ** [Calc](#) 📄

How many Ice Breakers are assigned in each district ** [Calc](#) 📄

Total economic impact of waterway closures after icebreaker allocations [Calc](#) 📄

Total Economic Impact after closure summed by waterway and Day (\$) [Calc](#) 📄

Total Economic Impact for each district after closure summed by Waterway and Day [Calc](#) 📄

Difference in total economic impact for alternatives for each district [Calc](#) 📄

Other Features and Information

[Advanced User Controls](#) ← [Model Details and Algorithms](#)

Figure 2. Basic user interface.

3.1 Basic User Inputs

The “Basic User Inputs” found in the basic user interface allow the user to set initial conditions for the model regarding the inventory of icebreakers and the severity of winter conditions. First, the user selects the number of ice breaking vessels of each cutter class that could be used for ice breaking by each District over the course of an ice season, assuming that other missions and unplanned maintenance do not make a particular asset unavailable for ice breaking in a particular day.

To set a “baseline” number of assets of each cutter class that applies for the entire ice season, select the variable “**Baseline Inventory of Icebreakers**” and revise the table that appears.

To make mid-season, or week-by-week, modifications to the “baseline” number of assets of each type, select the variable **“Mid-Season Icebreaker Inventory Adjustments”** and edit the table that appears. The values in the table indicate a mid-season change in comparison to the “baseline” values. For example, a value of 1 in a particular week for a particular type of asset means that one additional icebreaker of that type will be added to the “baseline” inventory during that week. Similarly, a value of 0 in “Mid-Season Icebreaker Inventory Adjustments” indicates that there is no change from the “baseline” inventory of that type of asset for that week. While the model simulates icebreaking operations on a daily basis, mid-season adjustments are only made on a weekly basis and apply to all days in the week.

Model version 2.0 enables the user to make icebreaker allocations for two alternative scenarios and run a comparison of the two alternatives in the model. Users are given the option to define the two scenarios based on both the baseline inventory and mid-season adjustment of icebreakers.

The basic user interface also allows the user to select the years of weather and ice data to use in the model using the variable **“User Choice of Specified or Randomly Selected Ice and Weather Data Years”** and the variable **“User Choice of Ice and Weather Data Years, if Applicable.”** The model can be run one of the following two ways:

- Random years, in which all years of ice data are used in the model calculation. Each iteration of the model randomly selects data from a given year, and after many Monte Carlo iterations have been run, the final model outputs reflect probabilistically representative risk profiles associated with that particular inventory of ice breaking assets; or
- Specified years, in which only a single year of ice data is used in the model calculations. The user must specify which year of ice data should be used in the drop-down menu.

To modify the value of one of the input variables, either click on the button to the right of the relevant text label or select a value from the drop-down menu. For example, to modify the “Baseline Inventory of Icebreakers,” click on the “Edit Table” button to the right of the input variable text. To choose random weather and ice data years, select “Random Years” for the input variable by clicking on the drop-down menu to the right of the text “User Choice of Ice and Weather Data Years, if Applicable.” Double-clicking on the label text of each variable, such as the text field for “Baseline Inventory of Icebreakers,” will show the documentation for that variable provided within the *Analytica*® model.

3.2 Basic User Outputs

The basic user interface displays the main model outputs, including economic impacts of waterway closures after icebreaker allocations. Three variations of economic impact outputs provide different ways for organizing or aggregating the same underlying set of economic impact calculations. These variations include:

- The variable **“Total Economic Impact for each district after closure summed by Waterway and Day,”** which indicates the economic impacts for each District summed across all days of the ice season; and

- The variable **“Total economic impact of waterway closures after icebreaker allocations,”** which provides the economic impacts for each waterway per day of the ice season.
- The variable **“Difference in total economic impact for alternatives for each district”** which provides the difference in economic impact for each district for the two alternative allocations specified.

To run the model and to obtain the values of one of the output variables, simply click on the button to the right of the relevant text label. For instance, to calculate the output variable “Total Economic Impact for each district after closure summed by Waterway and Day,” click on the “Calc” button to the right of the text.

3.3 Technical Specifications and Requirements

The model was developed using a 64 bit version of the “Optimizer” edition of Analytica®. Primary model testing and execution was completed using the same version of Analytica®, on a desktop operating system with the following specifications:

- Intel Core i7-2600 CPU@ 3.40 GHz
- 12 GB installed RAM
- 1TB Hard Drive
- 64-bit Windows 7 Operating System

In order to enable better model performance, virtual memory was manually managed, and set to a minimum file size of 80GB, this reduced response time during model run and improved overall performance.

Using these technical specifications, the model can consistently be calculated using 50 iterations, which required approximately 50GB of total memory usage.

Given a sufficiently sized hard drive, the number of iterations could be significantly increased, though at the expense of model run time. Currently a single model run takes 150 minutes to complete.

If the model returns an error message indicating that it has insufficient memory, the number of Monte Carlo iterations should be reduced. To do this, open the “Result” menu at the top of the *Analytica*® window, then open the “Uncertainty Options” sub-menu. Set the “Sample Size” to a lower number and click “Apply.” Re-run the model to produce the output variable values.

The “Enterprise” edition of Analytica® can be utilized to reduce the number of variables calculated that are stored in memory. This process increases the total number of possible iterations available, though will increase the time required to execute the model. Adjustments made to the model under the “Enterprise” edition would still hold for all subsequent users of the model, regardless of their Analytica® interface.

4 COMPREHENSIVE TOUR AND SCREENSHOTS OF THE MODEL'S MODULES

This section provides a graphical tour of the modules and sub-modules of the *Analytica*® model, accompanied by descriptions of the modules' functions. The user can browse the "live" displays of the model's modules using the basic user interface of the model. The screenshots presented in this section can be accessed by double clicking on the "Model Details and Algorithms" node in the "Other Features and Information" section of the basic user interface.

Figure 3 displays the first screenshot viewed upon entering the "Model Details and Algorithms" node. Figure 3 provides a conceptual overview of the DOMICE model and the relationships between the model's three main modules. These three main modules are: the "Ice Breaking Demand" module; the "Ice Breaking Supply" module; and the "Economic Impact" module, which alternatively is named the "DOMICE Economic Impact" module in the model. As the arrows between the nodes imply, the calculated "DOMICE Outcomes" of the model depend on both the "Ice Breaking Demand" module and the "Ice Breaking Supply" module. The "Economic Impact" module impacts both the Supply and Demand modules. Section 4.1 defines the general variables used throughout the DOMICE model. Sections 4.2, 4.3, and 4.4 will explore each of three main modules and their sub-modules in detail. Section 4.5 will discuss the outcomes of the DOMICE model.

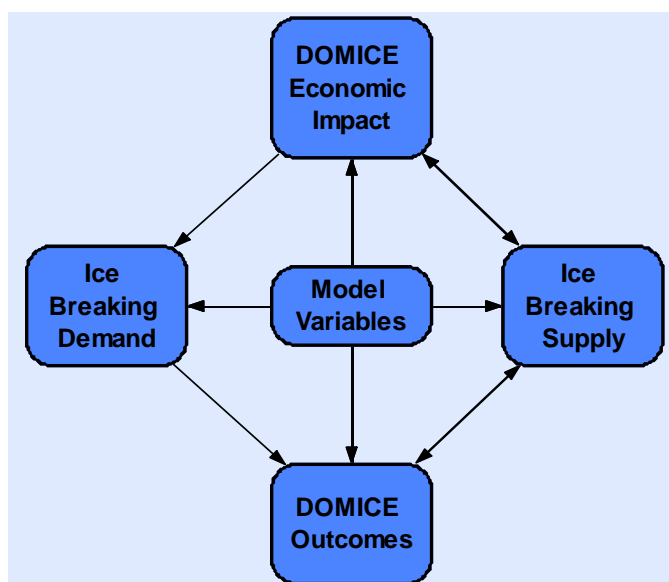


Figure 3. Overview of the DOMICE model.

4.1 Model Variables

As Figure 3 above indicates, the "Ice Breaking Demand" module, the "Ice Breaking Supply" module, the "Economic Impact" module, and the "DOMICE Outcomes" are all defined in terms of common "Model Variables." These "Model Variables" are used consistently throughout the model's sub-modules and refer to factors that define the scope of the DOMICE model. By double clicking on the "Model Variables" node of the Figure 3 screenshot, the screenshot in Figure 4 will appear that demonstrates the principal model variables.

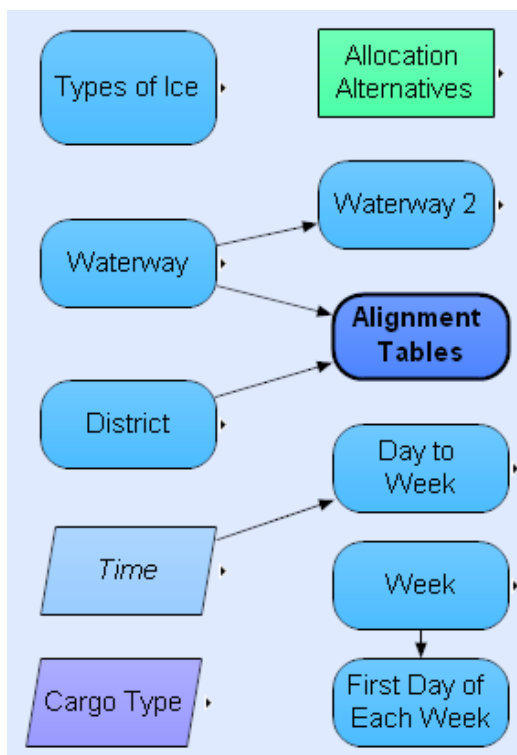


Figure 4. Model variables.

The “Districts” considered by the model are District 1 on the East Coast and District 9 on the Great Lakes. District 5 in the Mid-Atlantic region is not included in the model’s analysis. While the user can change asset assignments from one District to the other, the distinction between District 1 and District 9 waterways and ice breaking assets is preserved throughout all processes of the model.

The “Waterway” variable consists of all Tier 1 and Tier 2 waterways in Districts 1 and 9. The waterways used in the model’s analysis are constant throughout all the sub-modules.

“Types of Ice” on waterways is an important variable used throughout the model. All ice data is classified into the following three categories of ice: solid level ice; loose brash ice; and packed brash ice.

“Allocation Alternatives” specify the number of alternative scenarios that can be evaluated in the model.

“Time” is defined in the model as each day in the ice breaking season, which is assumed to be 140 days long. The model uses a daily time step within all modules and sub-modules.

While a number of changes were made throughout the development of model version 2.0, the single largest change made was to the model time step. While version 1.0 was calculated on a weekly basis, version 2.0 was calculated on a daily basis. In addition to the change in the definition of the System Variable “**Time**,” a number of variables were converted from a weekly basis to a daily basis. This alteration makes frequent use of the “aggregate” function in Analytica®.

The “Week”, “Day to Week” and “First Day of Each Week” variables are all used to aid in the conversion of the version 1.0 weekly time step to the version 2.0 daily time step.

4.2 Ice Breaking Demand Module

The “Ice Breaking Demand” module incorporates waterway-specific ice data and vessel traffic data to determine the demand for ice breaking assets on each waterway for each day of the winter navigation season. The module consists of two main sub-modules. The “Waterway Ice Characteristics and Ice Data” sub-module is used to process ice data in order to determine whether ice would impede normal vessel traffic on specific waterways each day, in the absence of ice breaking assets. The second sub-module, or the “Waterway Criticality” sub-module, is used to process vessel traffic data in order to prioritize ice breaking activities by ranking waterways in order of their commercial importance. Figure 5 demonstrates the structure of the “Ice Breaking Demand” module.

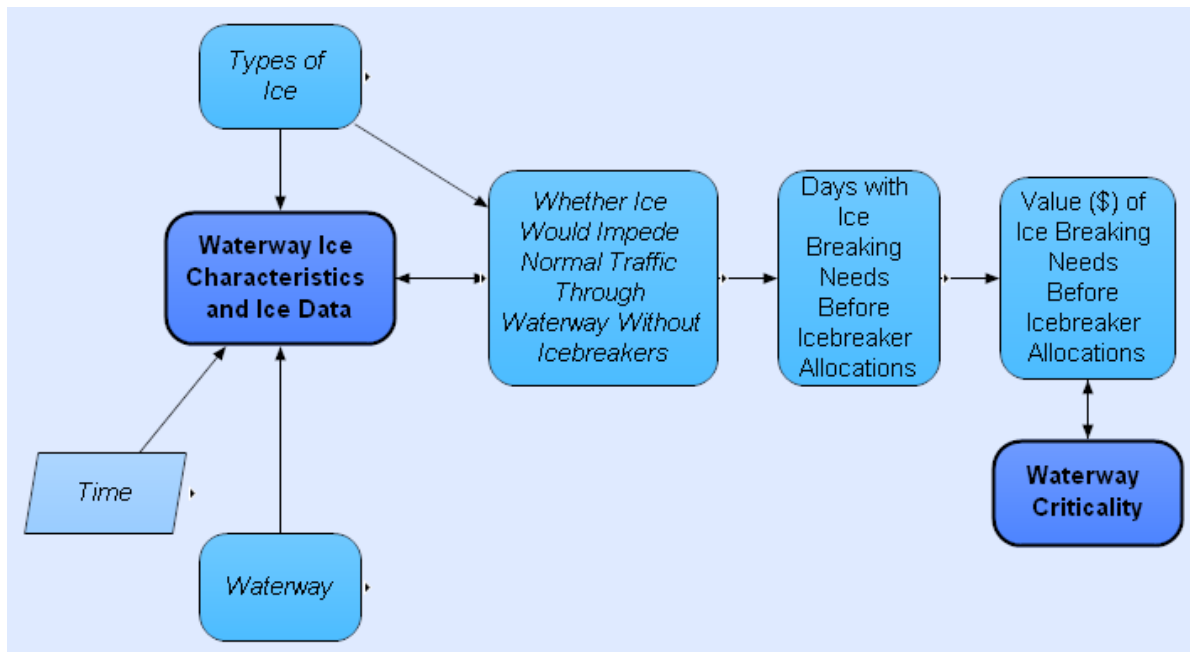


Figure 5. Ice breaking demand module.

4.2.1 Waterway Ice Characteristics and Ice Data Sub-Module

The sub-module uses historical ice data to determine on a weekly basis the maximum thickness of ice present on each waterway, which is characterized by the type of ice present. The weekly data is then applied to all days in that week. Based on the maximum thickness of each type of ice in the waterway, the sub-module determines whether the ice would impede normal traffic on each waterway in the absence of icebreakers, and whether the various types of icebreakers would be capable of breaking the maximum thickness of ice present on each waterway. Figure 6 demonstrates the processes and sub-modules used within the “Waterway Ice Characteristics and Ice Data” sub-module to determine waterway ice characteristics.

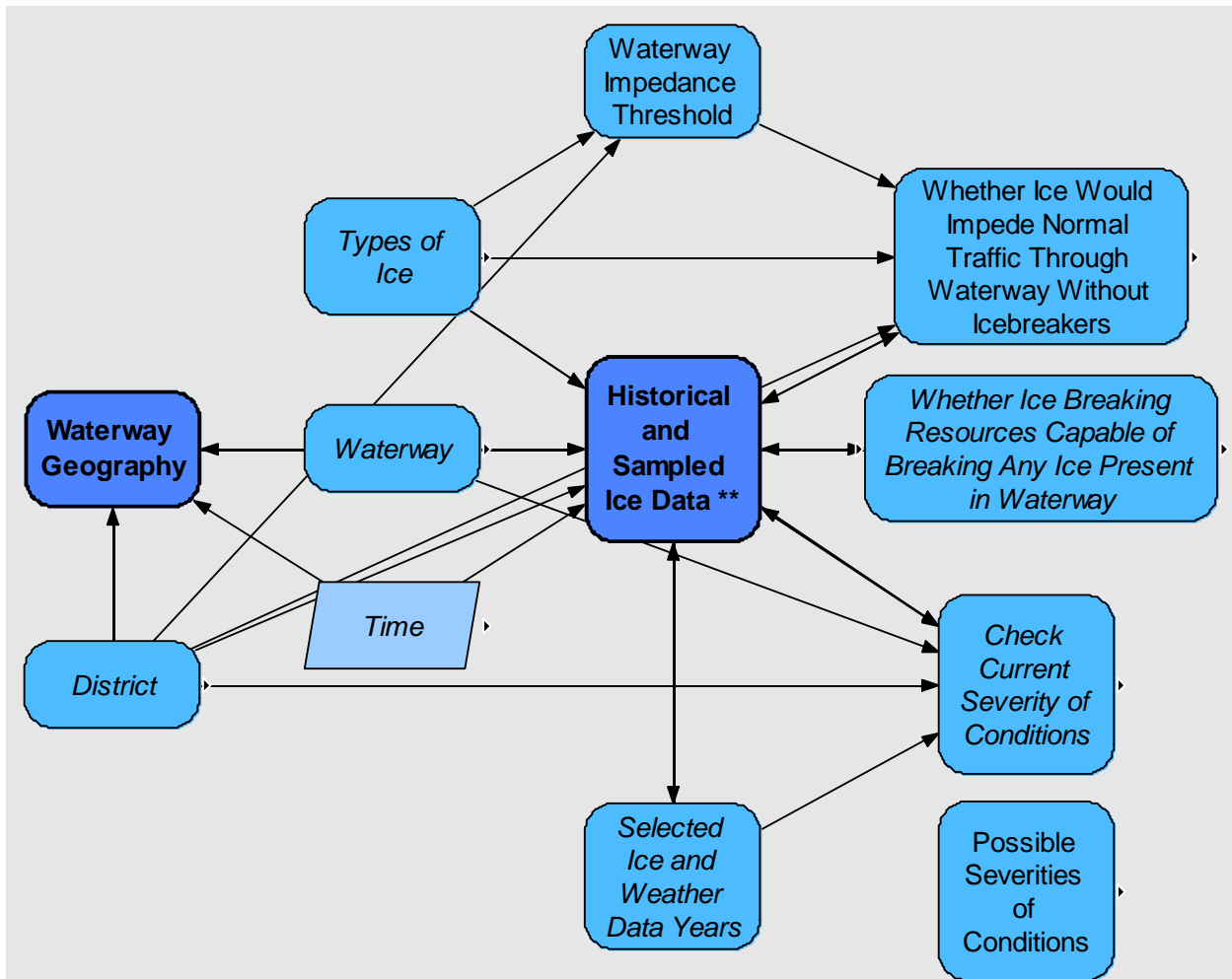


Figure 6. Waterway ice characteristics and ice data sub-module.

The “Waterway Geography” sub-module, displayed in Figure 7, provides geographical information specific to each waterway in order to match each waterway with its corresponding ice characteristics. Information regarding the waterway’s location, length, and District to which it pertains is provided for all Tier 1 and Tier 2 waterways. Information from the “Waterway Characteristics” sub-module feeds into the “Historical and Sampled Ice Data” sub-module.

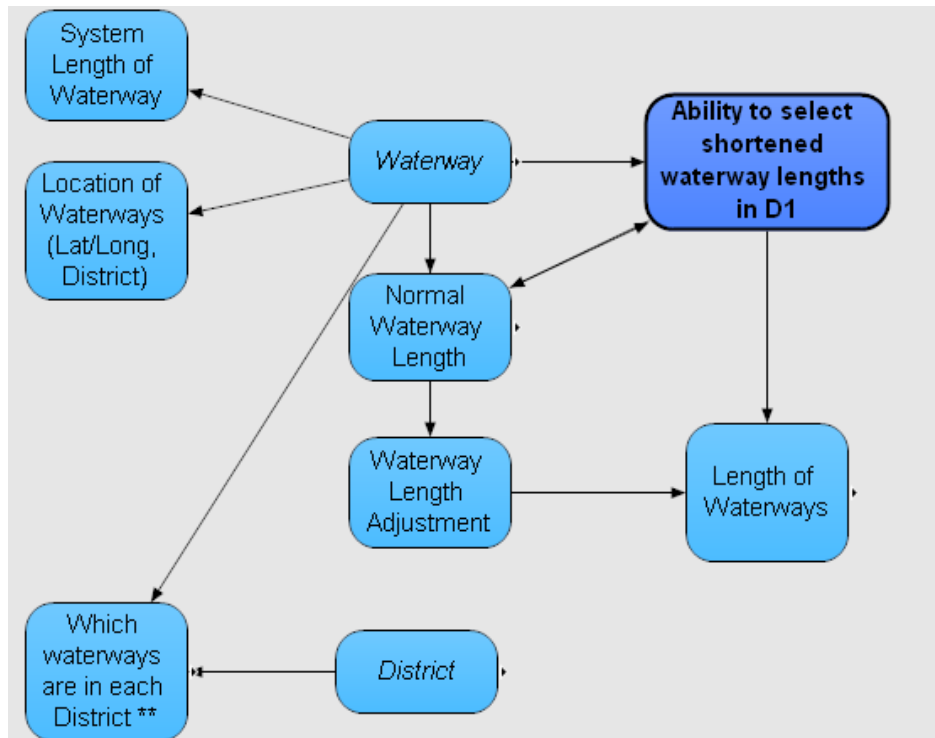


Figure 7. Waterway geography sub-module.

The length of several District 1 waterways (e.g., Connecticut River) were determined to require variable selections in length to allow users to select a normal length of the waterway, or a “short” length of the waterway. Figure 8 shows the sub-module that provides users the ability to select shortened versions of waterways.

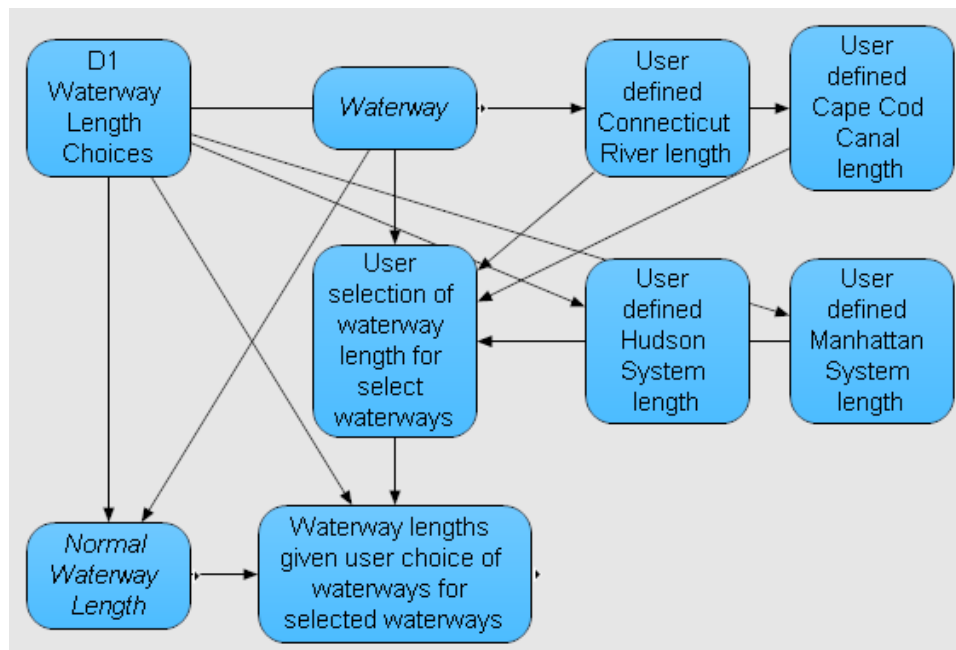


Figure 8. Ability to select shortened waterway lengths in D1 sub-module.

Depending on the District, the “Historical and Sampled Ice Data” sub-module either defines or models each waterway’s ice characteristics and ice data for each day of the ice breaking season. Disparities between the types of ice data available for each District required the sub-module to use statistical ice simulation models to determine ice thickness in District 1, whereas historical ice data was used to determine ice thickness in District 9. Figure 9 below shows the processes and sub-modules of the “Historical Sampled Ice Data” sub-module.

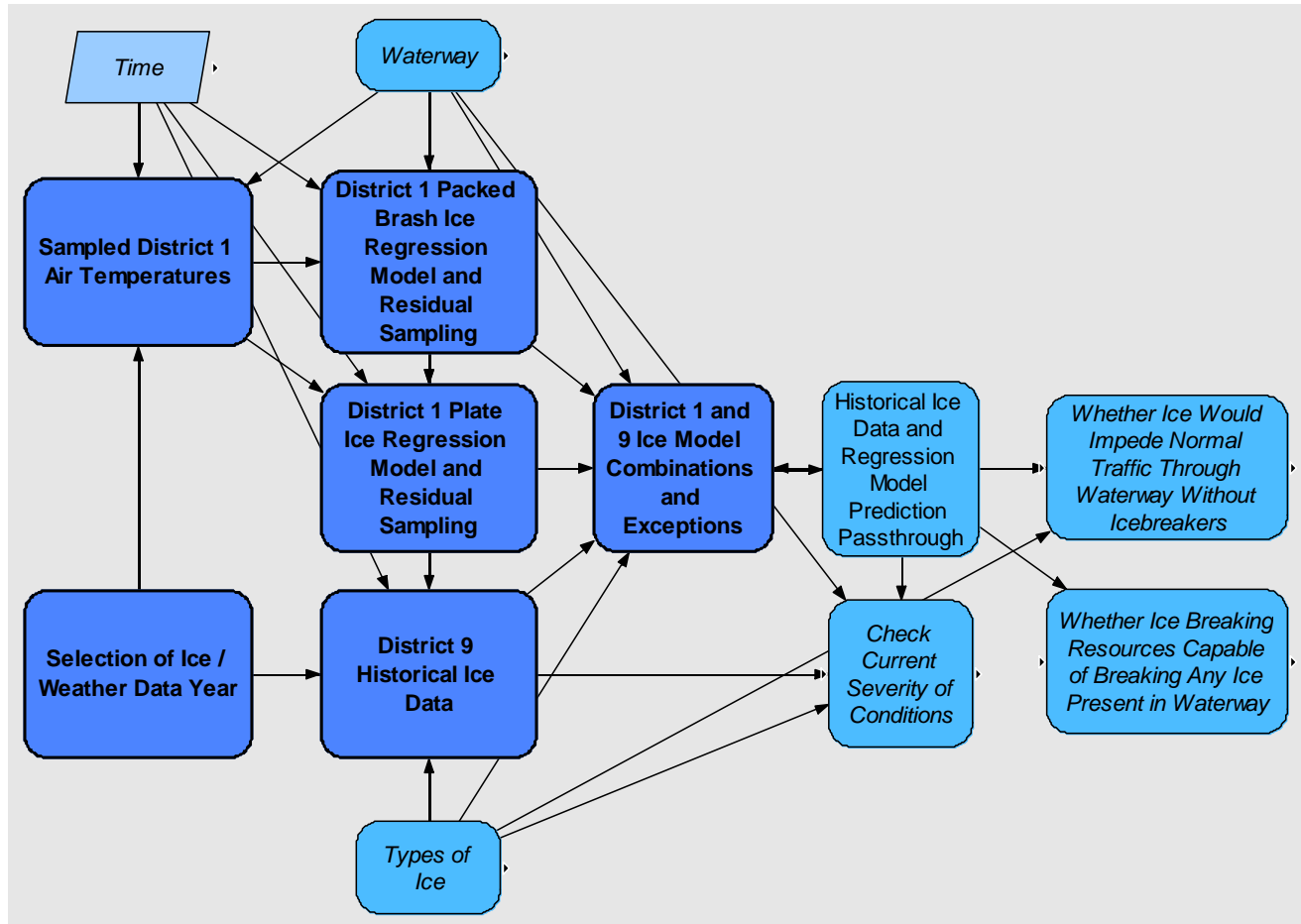


Figure 9. Historical and sampled ice data sub-module.

For District 9, the determination of ice thickness on each waterway is based upon historical ice data from 1998 to 2011. The National Oceanic and Atmospheric Administration (NOAA) National Ice Center generates weekly or semi-weekly ice reports for the Great Lakes. Discrete Global Positioning System (GPS) coordinates are used to define the geometric “shape” of the ice cover in the Great Lakes, and attributes of each outlined area are provided in terms of ice codes recorded as Sea Ice Grid (SIGRID) code values established by the World Meteorological Organization (WMO). The “District 9 Historical Ice Data” sub-module, shown in Figure 10 below, converts the SIGRID ice codes to the feet of ice thickness present on each waterway. Once the thickness of ice on a given waterway is determined, the sub-module can characterize the ice in terms of thickness of each of the three types of ice to determine if the ice would impede vessel traffic. To account for variability in ice thickness, the model allows the user either to select a specific year of District 9 historical ice data, such as ice data for the ice season 2008 to 2009, or to randomly

select a particular year's ice data in each Monte Carlo iteration. Data was only available from NOAA on a weekly basis. Model version 2.0 uses the weekly data for ice conditions and applies it to all days within the week. Other information, such as vessel traffic, is considered on a daily basis.

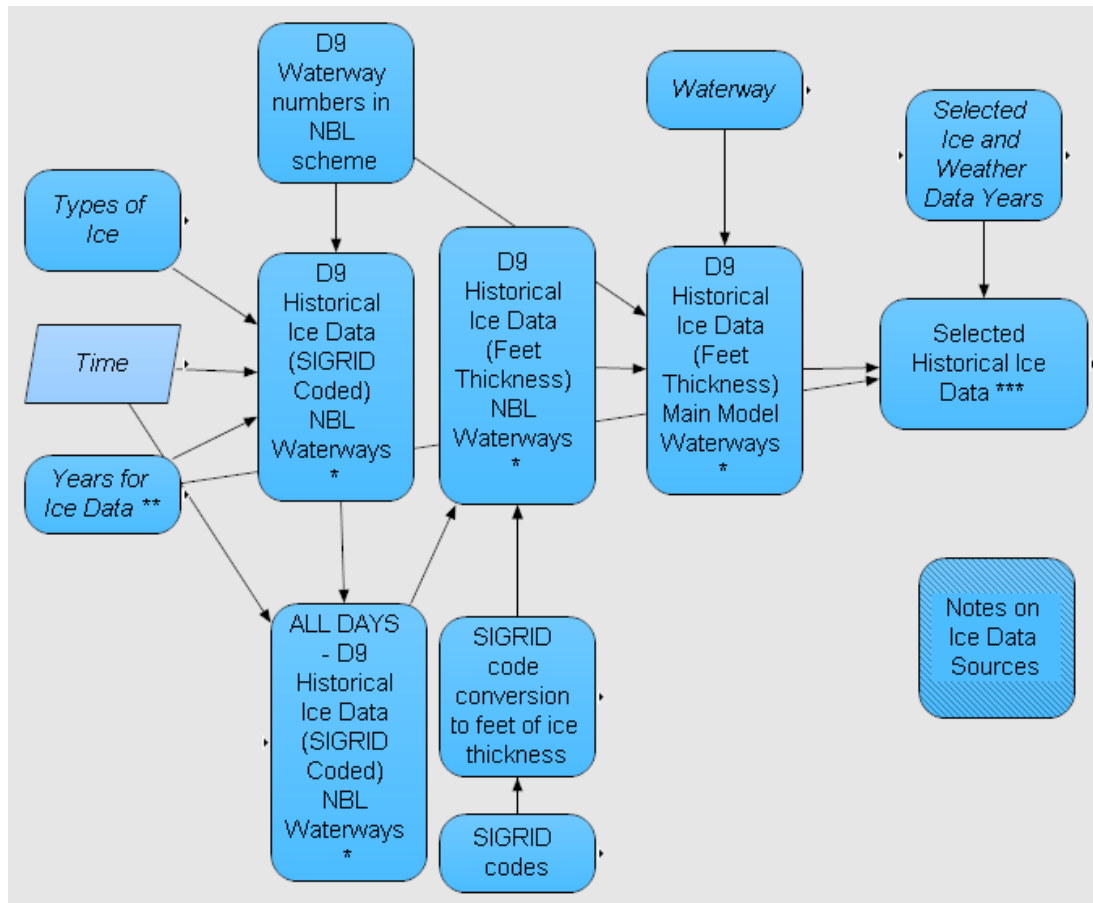


Figure 10. District 9 historical ice data sub-module.

Unlike in District 9, there is no quantitative data currently available in District 1 that measures the ice thickness on critical waterways in past winter navigation seasons. The only information available for ice conditions consists of USCG ice reports that, while useful in validating the model's results, are qualitative in nature and cannot be quantified in a meaningful way for input into the model. Because of these restrictions in data availability, historical meteorological data is used to simulate past ice conditions in District 1. Figure 11 below shows the "Sampled District 1 Air Temperatures" sub-module.

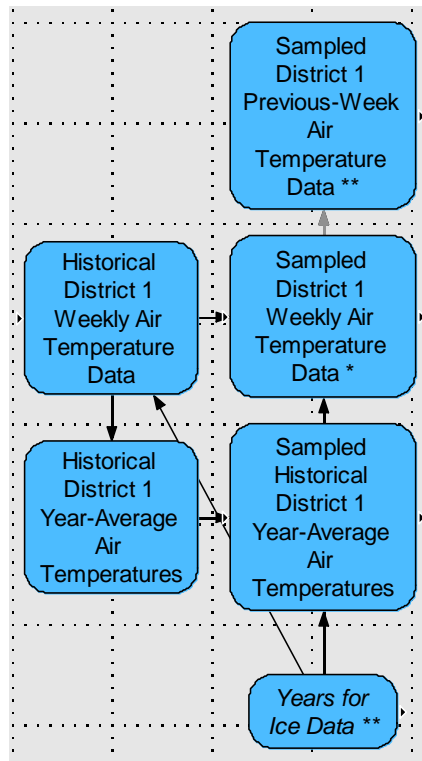


Figure 11. Sampled District 1 air temperatures sub-module.

Specifically, the sub-module uses air temperature as an indicator of ice formation¹. Regression models were created to first correlate District 9 historical air temperatures with District 9 historical ice data, and then to correlate this relationship to the historical air temperature data for District 1 waterways. By modeling this relationship between air temperature and ice thickness, the thickness of ice that would be present on each District 1 waterway is simulated based on the air temperature data. The District 1 weather-ice regression models include both linear terms for the influence of air temperature on ice formation and probabilistic error terms for regression residuals in which ice formation is not explained by the linear terms. The District 1 weather-ice regression models are defined for each week in the ice season, in order to better simulate the time-series profile of ice formation over the course of an ice season. Figures 12 and 13 demonstrate the processes involved in the District 1 Regression Models for both Packed Brash Ice and Plate Ice. Figure 14 shows the “District 1 and 9 Ice Model Combinations and Exceptions” sub-module, which includes the conversion of weekly results from the D1 regression into daily ice values.

¹ White, K. (2004). Method to Estimate River Ice Thickness Based on Meteorological Data. Ice Engineering. Hanover, New Hampshire, U.S. Army Engineer Research and Development Center Report. ERDC/CRREL Technical Note 04-3.

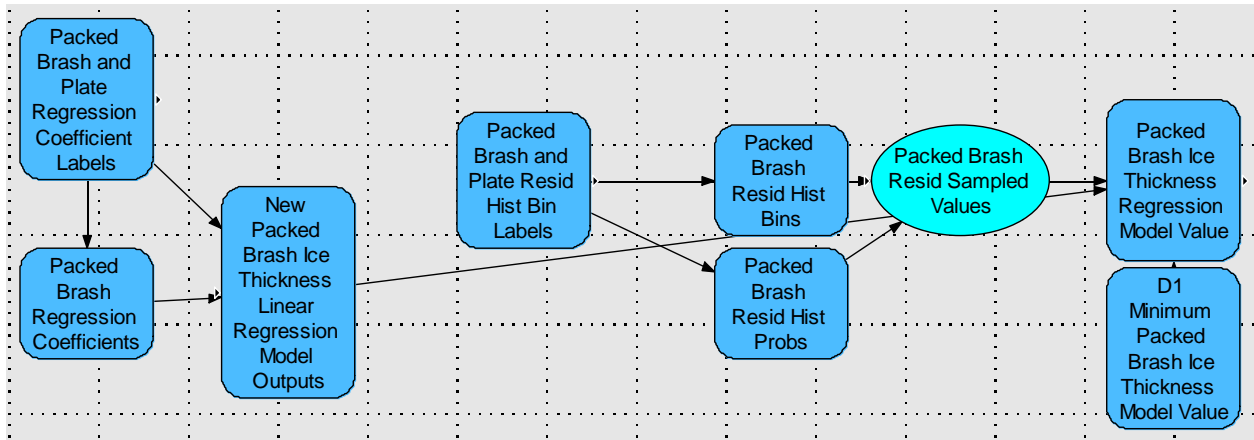


Figure 12. District 1 packed brash ice regression model and residual sampling sub-module.

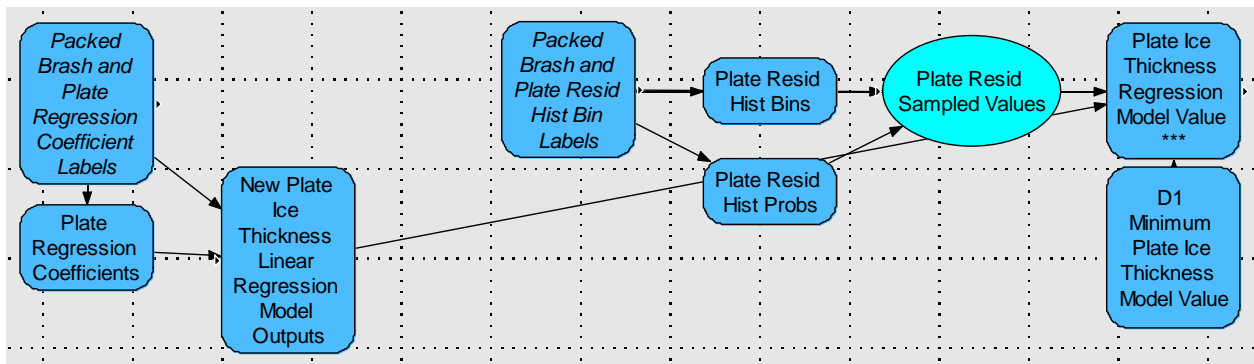


Figure 13. District 1 plate ice regression model and residual sampling sub-module.

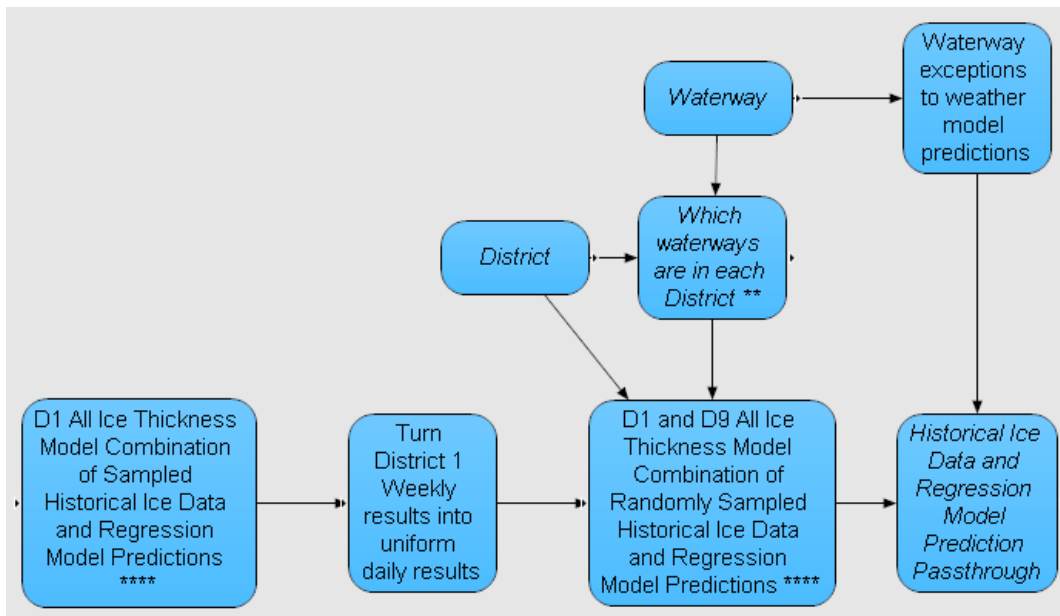


Figure 14. District 1 and 9 ice model combinations and exceptions sub-module.

In addition to the thickness of each type of ice, the sub-module accounts for a separate dimension of weather severity through the “Selection of Ice / Weather Data Year” sub-module shown below in Figure 15. Approximately one ice season in ten is regarded as severe. For example, the 2002 to 2003 ice season was regarded as a severe winter in District 9. For both Districts, but primarily in District 1, variability in the severity of ice conditions is incorporated into the “Historical and Sampled Ice Data” sub-module by using severity-dependent assignment rules. Ice severity is determined by the “Selection of Ice / Weather Data Year” sub-module based on the District. Ice conditions in District 1 are considered “severe” if the sub-module indicates that the Cape Cod Canal is iced over for a week². In District 9, ice conditions are considered “severe” if either the sub-module or the user sets the ice data year to 2003, or in other words, selects the 2002-2003 ice season.

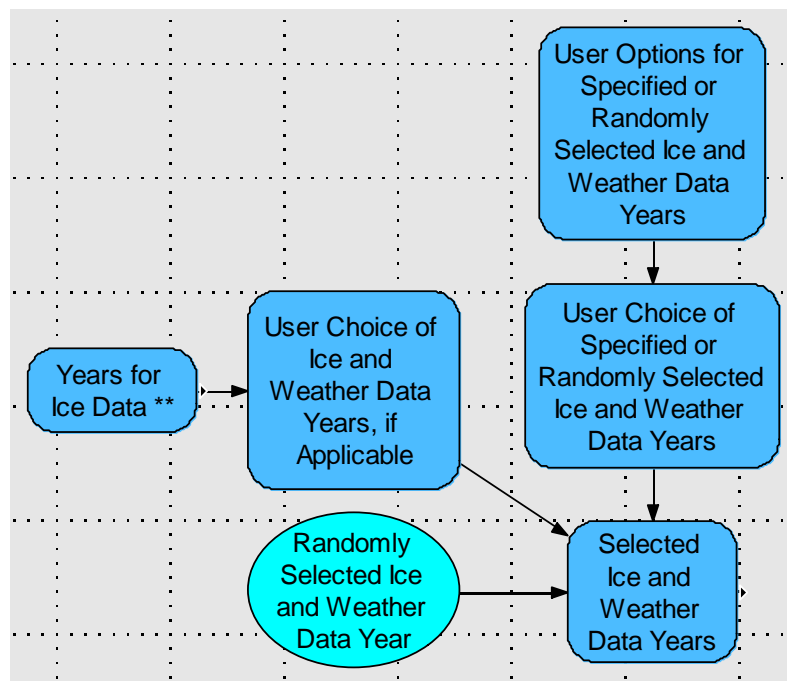


Figure 15. Selection of ice/weather data year sub-module.

4.2.2 Waterway Criticality Sub-Module

The second sub-module of the “Ice Breaking Demand” module, or the “Waterway Criticality” sub-module, utilizes historical vessel traffic data to determine the relative importance of waterways in terms of the vessel traffic flow that they support. Based on historical daily AIS data inputs, the sub-module assesses the number of unique vessels transiting a waterway each day of the winter navigation season. The number of unique daily transits is combined to determine the total number of vessel passes through a waterway over the course of an ice season. The sub-module accounts for the probability of varying levels of traffic flow through a probabilistic simulation based on historical data.

Inputs from the “Economic Impact” module, which will be discussed in detail in Section 3.4, are used within the vessel traffic sub-module to determine the criticality of each waterway in terms of the value of

² This definition of a “severe” winter season in District 1 is based on SME input collected in a DOMICE stakeholder meeting.

economic commerce moving through each waterway. Waterway criticality affects the demand for ice breaking assets in each District, and therefore, is an important component of the “Ice Breaking Demand” module. As an example of the interconnected structure of the DOMICE model, water criticality is also an important input used by the “Ice Breaking Supply” module in determining the assignment of ice breaking assets to waterways. Figure 16 below demonstrates generally how water criticality is determined.

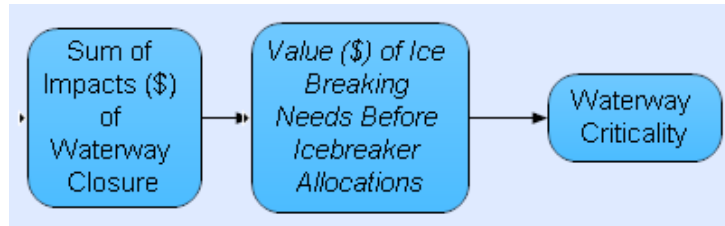


Figure 16. Waterway criticality sub-module.

4.3 Ice Breaking Supply Module

Figure 17 shows the structure of the “Ice Breaking Supply” module, which examines the availabilities and capabilities of the icebreaker fleet. Several kinds of information are included regarding ice breaking assets, such as: the inventory of icebreaker vessels in the fleet; the functional characteristics of each cutter class; and the unavailability rates of the assets due to other USCG missions and unplanned maintenance. Each of these factors is processed through a sub-module of the “Ice Breaking Supply” module and will be discussed separately here. The module uses these types of information on vessel characteristics, along with ice data from the demand module, to calculate whether a particular type of ice breaking asset would be capable of breaking the ice present in each waterway for a given model run. Each vessel’s capabilities and availabilities within a specific model scenario are ultimately used to determine the allocation of ice breaking vessels to waterways in each District through a separate sub-module.

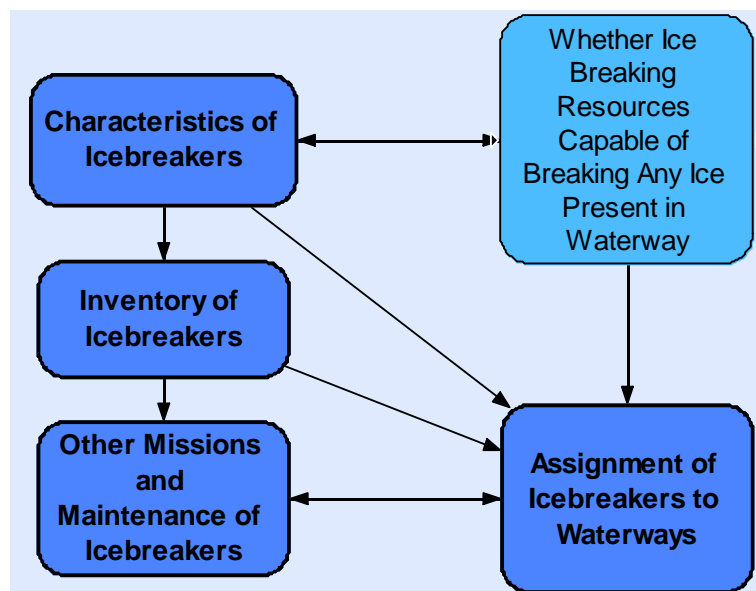


Figure 17. Ice breaking supply module.

4.3.1 Inventory of Icebreakers Sub-Module

Figure 18 represents the “Inventory of Icebreakers” sub-module. Both ice breaking assets of the US domestic fleet and of the Canadian fleet are considered. The location of each ice breaking asset is defined in terms of the District to which it is assigned and the overall inventory of icebreakers available during the ice breaking season. The user can manipulate the baseline inventory of icebreakers to assign any asset to one of the two Districts for the winter navigation season. Additionally, the user can adjust the inventory of available icebreakers in each District on a week by week basis as part of “mid-season icebreaker inventory adjustments.” The weekly adjustment is applied to all days in the week. The inventory of ice breaking assets is specified to the number of vessels per vessel class available for deployment, and does not include an assessment of unique characteristics or abilities of individual vessels within each vessel class.

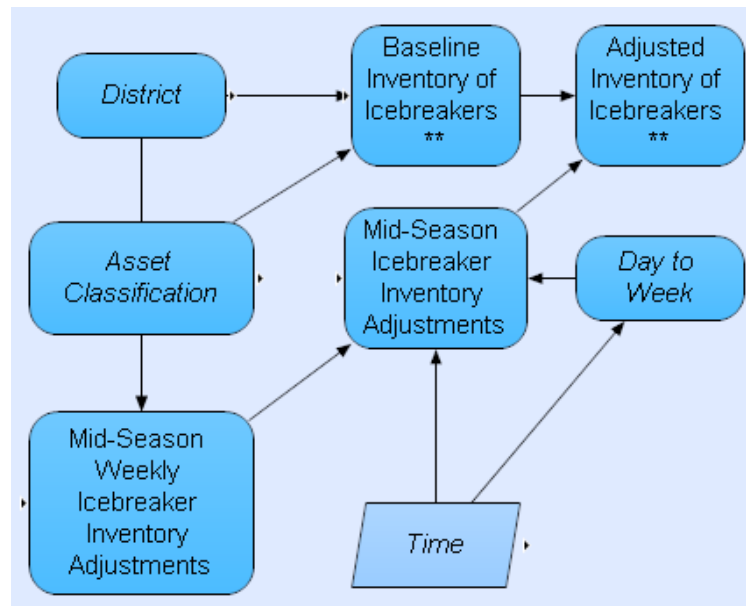


Figure 18. Inventory of icebreakers sub-module.

4.3.2 Characteristics of Icebreakers Sub-Module

The “Characteristics of Icebreakers” sub-module, shown below in Figure 19, incorporates a variety of factors that affect the capability of assets to break ice in order to determine whether an icebreaker of a given cutter class is capable of breaking ice in a specified waterway. For each type of vessel, the sub-module defines ice breaking capabilities in terms of a vessel’s ability to break the three identified types of ice. The sub-module also considers vessel capabilities based on both the speed at which an icebreaker can operate and the number of passes needed per day to maintain a waterway open to traffic. The type of clearing activity conducted, which is either direct clearing of the waterway or indirect/preventative clearing, affects the speed and number of passes necessary. Weather conditions also impact the type of clearing activity conducted, which in turn depend on the District to which the waterway pertains. Two types of weather conditions are considered, namely “moderate” or “severe” conditions.

The number of passes required per day in order to maintain District 1 waterways open depend on the severity of weather conditions and the type of clearing activity conducted. Due to higher variation in ice breaking activities in District 9 than in District 1, the number of passes required per day in District 9 also varies by waterway and by time of the year. Transit time is also considered a characteristic of icebreakers, representing the number of days required for a vessel to be dispatched from one waterway to another. Transit time is calculated in a separate sub-module.

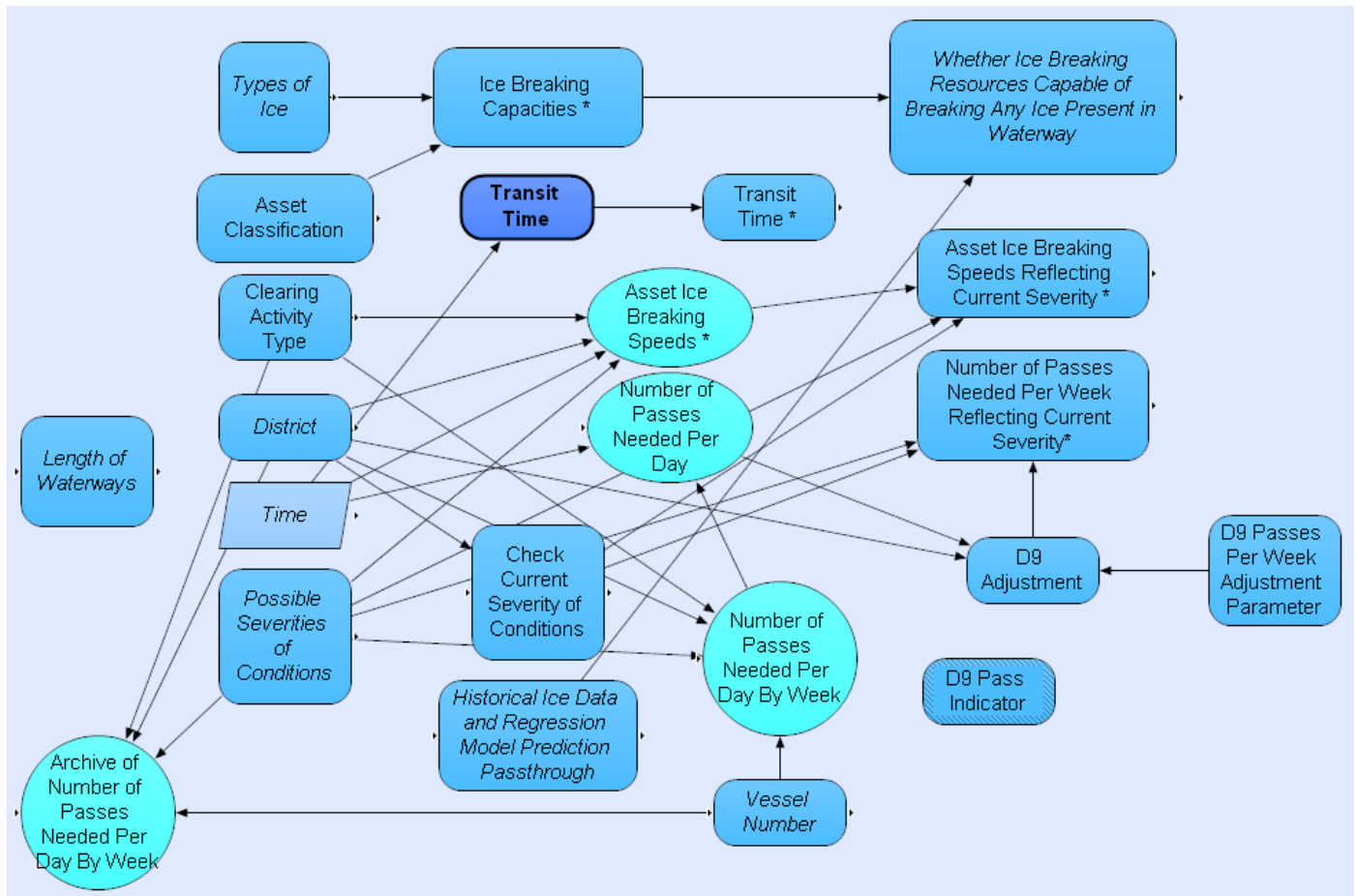


Figure 19. Characteristics of icebreakers sub-module.

The transit time sub-module, shown in Figure 20, calculates transit time for each day based on the distance between the various waterways and the deployment of icebreakers on the previous and current days.

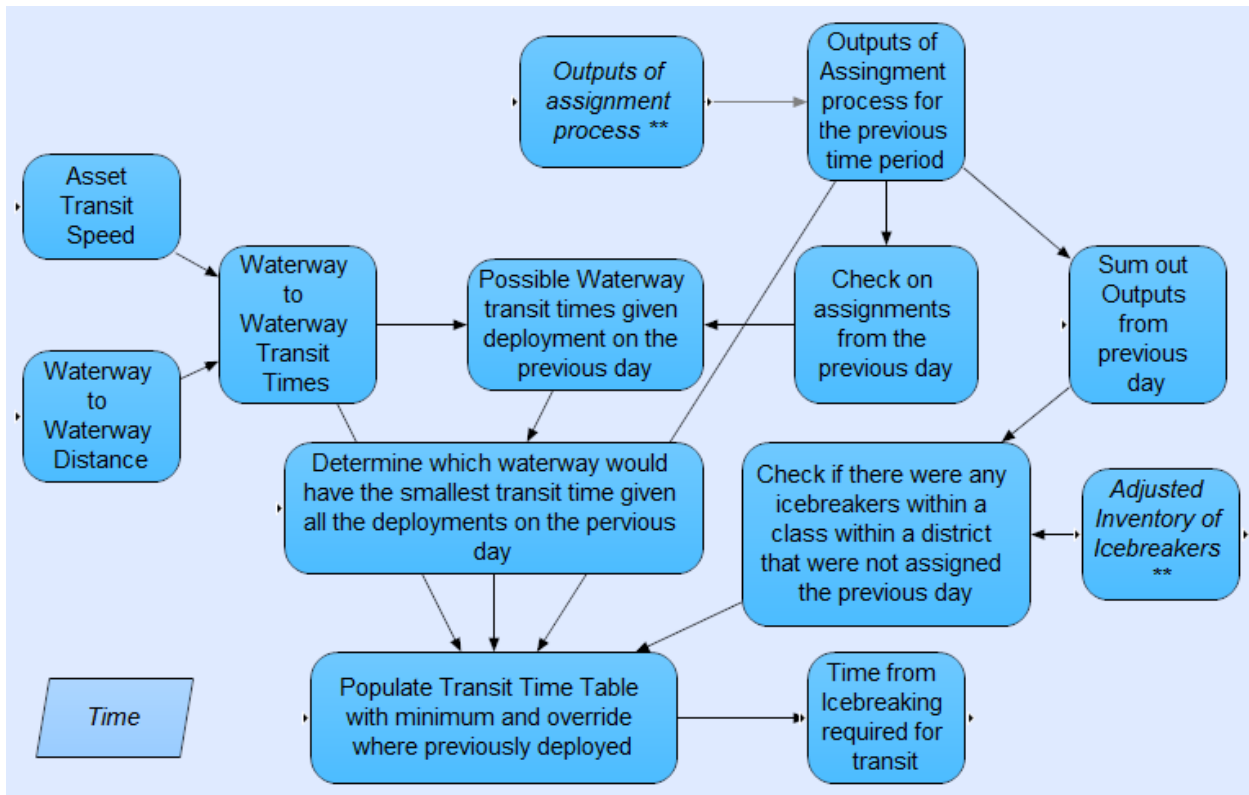


Figure 20. Transit time sub-module.

4.3.3 Other Missions and Maintenance of Icebreakers Sub-Module

The “Other Missions and Maintenance of Icebreakers” sub-module, shown below in Figure 21, accounts for the probability of a vessel being unavailable for ice breaking activities. Two causes for icebreaker unavailability are considered in the module, namely, asset unavailability due to maintenance downtime and asset unavailability due to assets being assigned to other USCG missions as priority over ice breaking for commercial traffic. Based on the calculated number of available cutter hours and the capability of each cutter class, total available ice breaking availability is calculated for each day in the ice season.

This sub-module determines the unavailability of assets due to maintenance based on the historical availability data from the “USCG DOMICE Mission Analysis Report (MAR),” presented as the percent of time each asset is free from major casualties. The 240 WLBB is the only cutter class that does not follow the availability rates found in the MAR. This vessel had 100 percent availability rates in each of the three years since it was serviced, but the MAR establishes only a 95 percent availability target. In the sub-module, it was assumed that the 240 WLBB would have a 100 percent availability probability half of the time and a 95 percent availability the other half of the time.

As for unavailability of assets due to other USCG missions, the default settings of the sub-module assume that there are no missions, whether Aids to Navigation (ATON), Ports, Waterways and Coastal Security (PWCS), or Search and Rescue (SAR), that demand enough hours while there is a demand for ice breaking to significantly reduce the availability of assets for breaking ice. The sub-module can be adjusted, however, to assign hours of icebreaker assignments to these other missions at the user’s discretion.

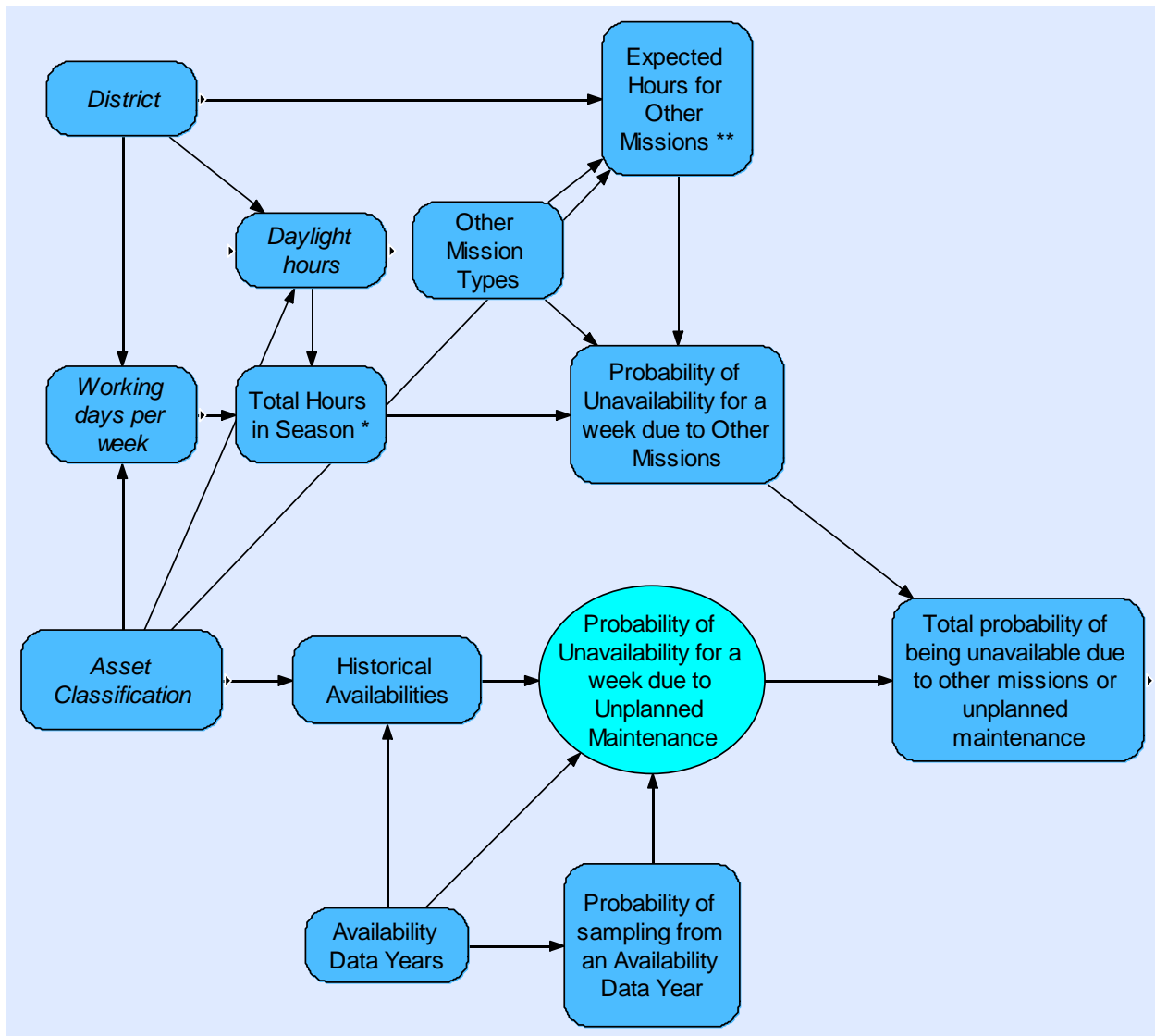


Figure 21. Other missions and maintenance of icebreakers sub-module.

4.3.4 Assignment of Icebreakers to Waterways Sub-Module

The three sub-modules described above each impact the “Assignment of Icebreakers to Waterways” sub-module, which assigns vessels of each cutter class to specific waterways for each day of the winter navigation season. The assignment process considers a wide range of factors to determine the sequential application of vessel assignments in an order that reflects assignment priorities within each District. Figure 22 below demonstrates the sub-modules incorporated into the “Assignment of Icebreakers to Waterways” sub-module.

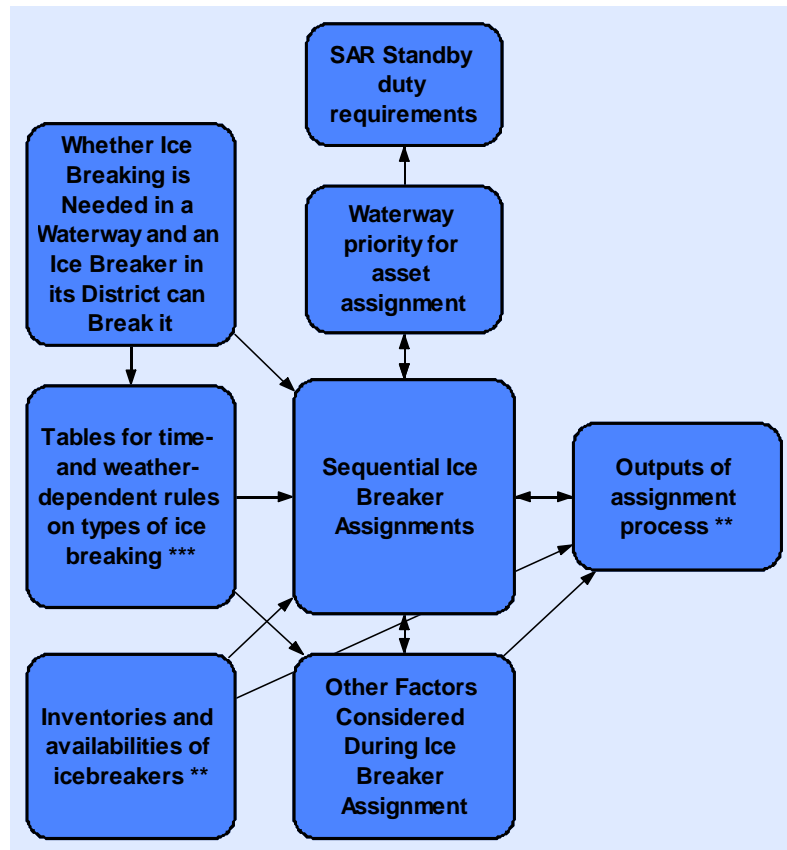


Figure 22. Assignment of icebreakers to waterways sub-module.

Several outputs from the other main modules discussed previously are used to influence asset allocation. Ice-related variables from the “Ice Breaking Demand” module are inputted to allow the sub-module to determine which waterways need ice breaking in each District. Figure 23 below demonstrates the ice-related variables used in the “Whether Ice Breaking is Needed in a Waterway and an Icebreaker in its District Can Break It” sub-module. The principal calculations performed by this sub-module are determining which waterways need ice breaking in each District, and which ice breaking assets would be capable of breaking the thickness of ice present. This consideration is important because assets in each District are assigned only to waterways in that District where the asset can break the ice present.

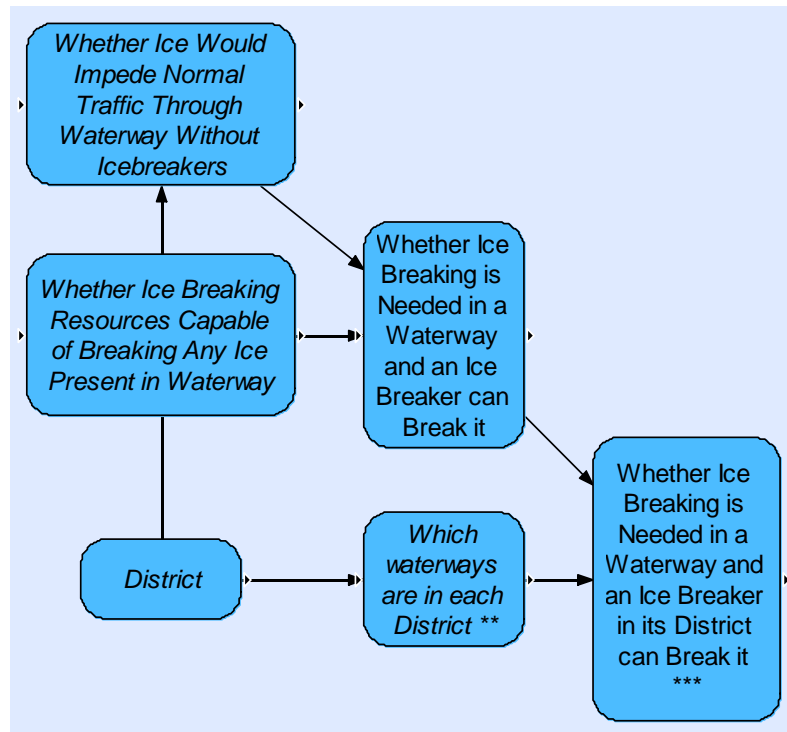


Figure 23. Whether ice breaking is needed in a waterway and an ice breaker in its District can break it sub-module.

The assignment process simulates uncertainty in the number of ice breaking assets of each cutter class that may be available in each District per day. The number of assets of each cutter type available for ice breaking each day is calculated in the “Inventories and Availabilities of Icebreakers” sub-module, seen in Figure 24 below, using the total inventories of ice breaking assets and the probabilities that any asset would be unavailable for ice breaking due to other missions or unplanned maintenance.

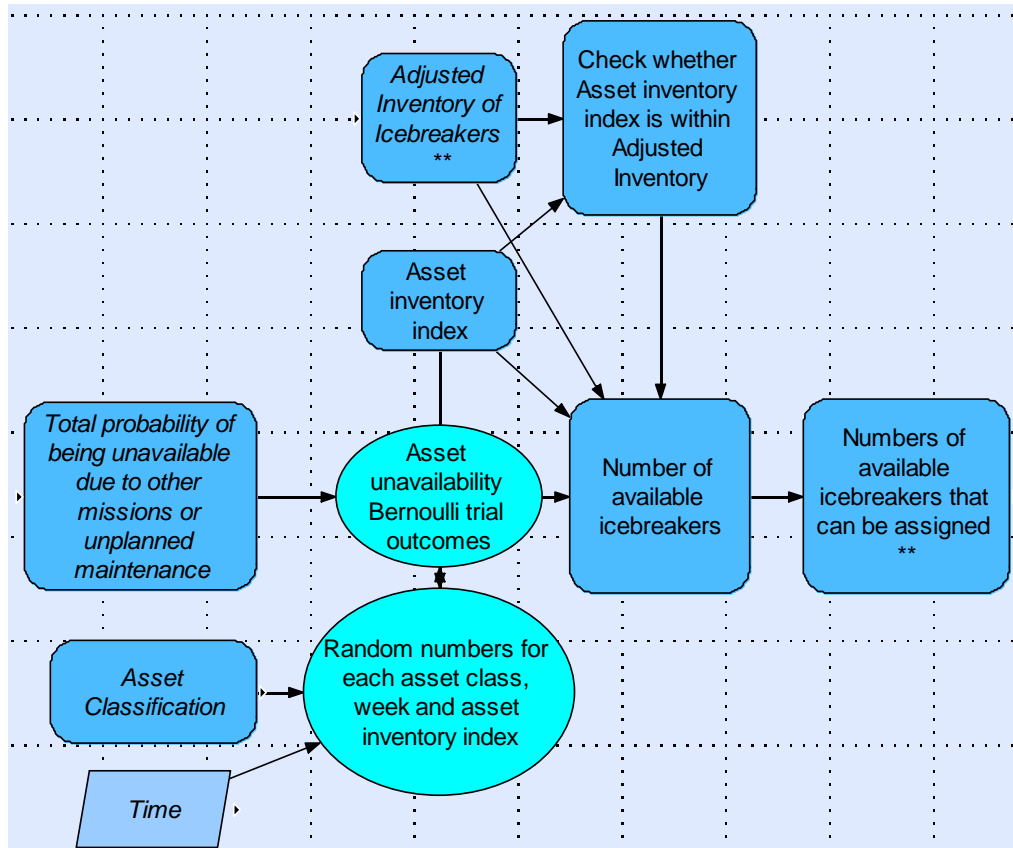


Figure 24. Inventories and availabilities of icebreakers sub-module.

To simulate requests for ice breaking activities, the “Sequential Icebreaker Assignments” sub-module uses a sequential application combining assignment rules and priorities of possible assignments. For each day of the ice season, the sub-module considers whether to assign one or two icebreakers of a particular icebreaker class, such as 65s or 140s, to perform either track maintenance or direct clearing in a waterway. The model first considers any assignments that have been specified in advance. The model then proceeds to make successive assignments of any remaining assets to whichever waterways satisfy all of the following conditions:

- Ice is present in a waterway and the specified vessel type is capable of breaking the thickness of ice present in the waterway;
- Assets remain available after the previous assignment;
- Assets would be sufficient for clearing the length of a waterway with the required number of passes per day. If one asset would be sufficient to clear the length of a waterway, then one asset would be assigned, but if two assets would be needed to clear the length of a waterway, then two assets would be assigned;
- Either track maintenance or direct/active clearing would be an appropriate activity in the current day. This would exclude, for instance, cases in which maintenance is not performed during the closed season in District 9; and

- The waterway is the highest assignment priority among the set of waterways that both meet all of the above conditions and do not yet have an appropriate icebreaker assigned to them. Priority reflects the SAR standby rules and advance assignment rules, as well as commercial importance of waterway traffic.

Figure 25 below demonstrates the processes involved in the “Sequential Ice Breaker Assignments” sub-module. The sequential assignment of assets is performed through a series of separate sub-modules, with each sub-module designed for a specific cutter class and a specific type of ice breaking activity. For instance, the assignment of 65s to track maintenance has a separate sub-module than the assignment of 140s to track maintenance. Similarly, the assignment of 65s to active/direct clearing has a separate sub-module than the assignment of 65s to track maintenance. Each of these sub-modules uses inputs from the other sub-modules of the “Assignment of Icebreakers to Waterways” sub-module to determine whether a waterway satisfies the conditions listed above.

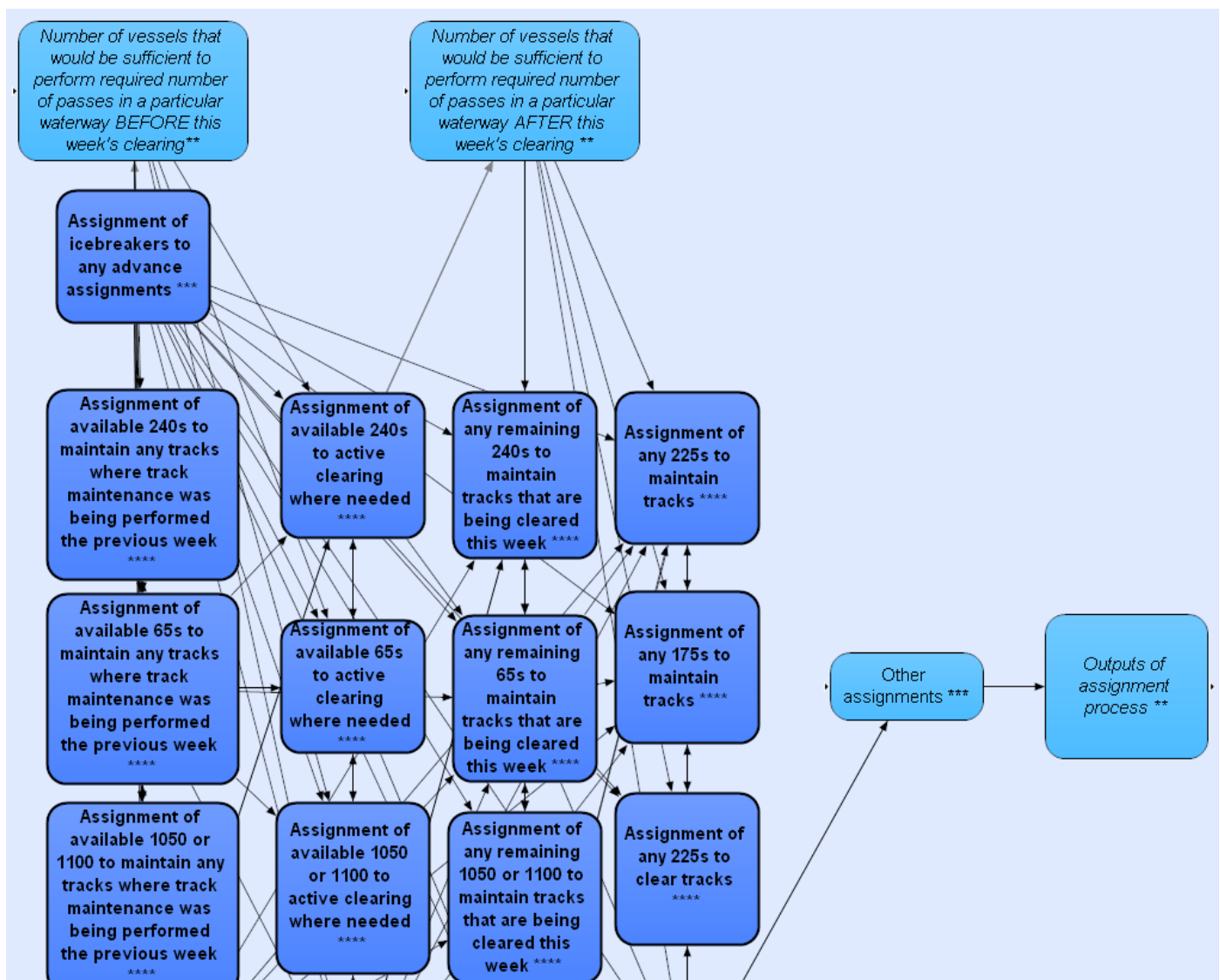


Figure 25. Sequential ice breaker assignments sub-module.

Vessel assignments are determined one asset or one pair of assets at a time in each District, in order to avoid exceeding available inventories of assets in the District. Once an assignment of one asset or one pair of assets is made, the module proceeds to consider making another assignment of the same type of asset. If all of the above conditions are not met by that asset type, the module does not make any more assignments of assets of that cutter class and, instead, considers the vessels of the next asset type. Once the module has made assignments for all the available assets in the current day, it then proceeds to determine assignments for the following day.

For each day, after making assignments specified in advance, the sub-modules consider assignments in the following order:

- 1) Assignment of assets to maintain any tracks where track maintenance was being performed in the previous day;
- 2) Assignment of assets to active clearing needed this day; and
- 3) Assignment of any remaining assets to maintain tracks that are being cleared this day.

At each of the numbered steps above, the assignment sub-modules also consider each class of ice breaking asset in a specific order that reflects the increasing capability of assets to break ice. This order is followed to focus the most capable assets to the waterways in which their capabilities would be put to greatest use. The 240 is assigned first by the sub-modules, and is usually assigned either to the Sault Ste. Marie System or the Detroit River System. The assignment of 65s is considered second, followed by the assignment of Canadian Assets, which are 1050s or 1100s. The 140s are considered for the next assignments. Lastly, the 225s and 175s are assigned, with 175s being the last cutter class considered. The 225s and 175s are the final vessels considered for assignment due to their role as backups to other assets in the fleet and to ensure that these assets are only used if all vessels of other cutter classes are not able to meet ice breaking needs. Based on the order of ice breaking assignment types and the order in which the cutter classes are considered, the final assignment of the assignment process for each day is the assignment of 175s to clear tracks.

Figures 26 through 28 below are screenshots of several of the sub-modules used in the asset assignment process. Each sub-module contains the detailed procedures for the assignment of 240s, 65s, and 140s for track maintenance or active/direct clearing. Figure 26 is the first sub-module assigning assets, which assigns 240s to maintain tracks. Figure 27 is the second sub-module assigning assets, which assigns 65s to maintain tracks. Figure 28 is the final sub-module in the asset assigning process, which assigns 175s to clear tracks.

The successive assignment of assets to waterways is implemented in each sub-module using a series of vertically repeating assignment steps, as seen in Figures 26 through 28. This structure allows the sub-module to function in a way similar to that of calculations organized in a single column of a spreadsheet. For example, the second assignment step following the assignment of the 240 is for the first sequential assignment of available 65s to maintain any tracks where track maintenance was being performed the previous day. The calculations specific to that assignment step are organized horizontally. The calculations specific to the second assignment are found in the second row, and so on. Enough sets of calculations are provided to allow for up to ten assignments of 65s to a particular type of ice breaking activity, such as track maintenance, which exceeds the inventories of 65s in either District.

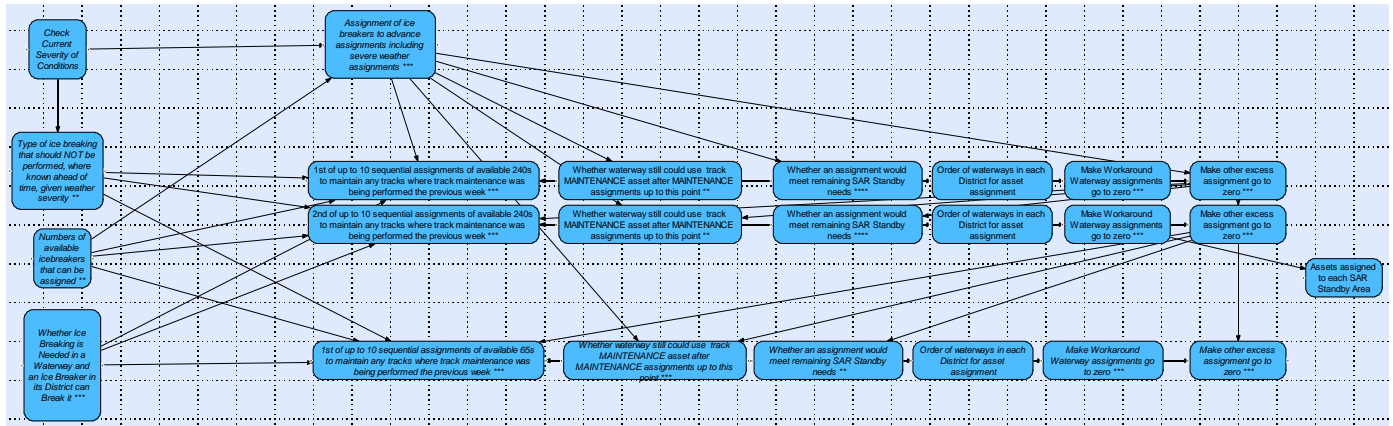


Figure 26. Assignment of available 240s to maintain any tracks where track maintenance was being performed the previous day sub-module.

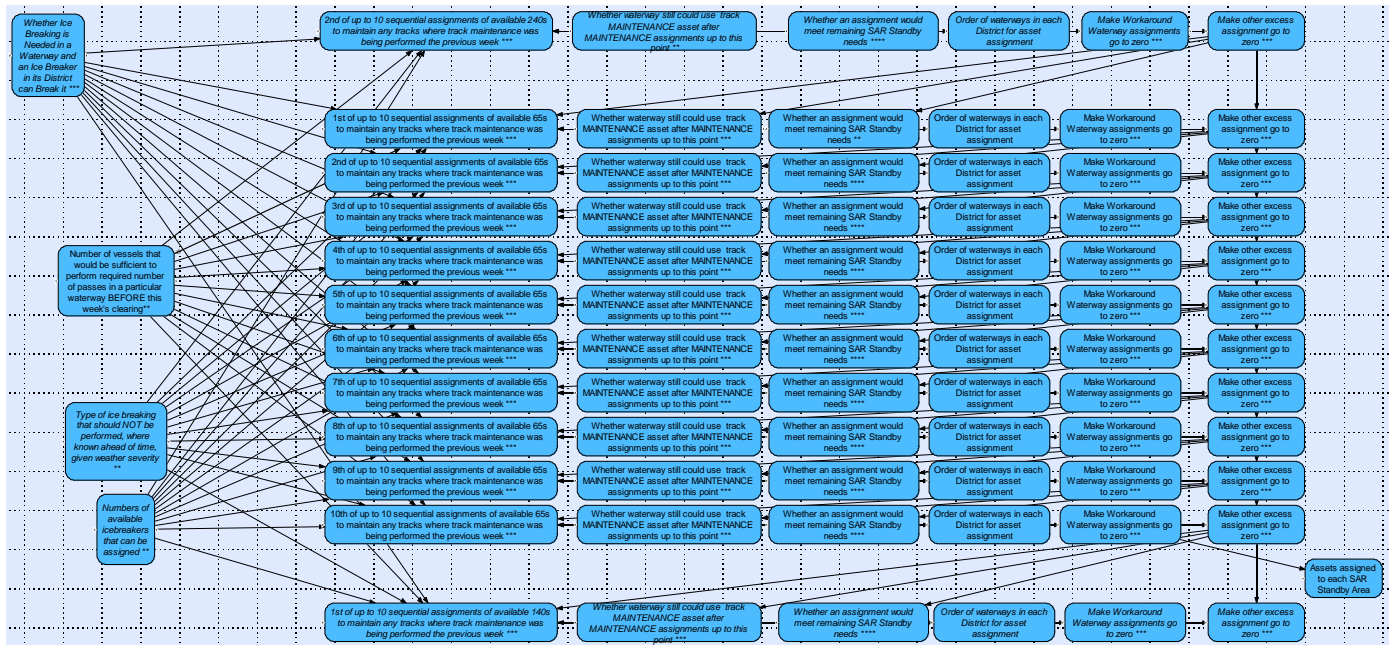


Figure 27. Assignment of available 65s to maintain any tracks where track maintenance was being performed the previous day.

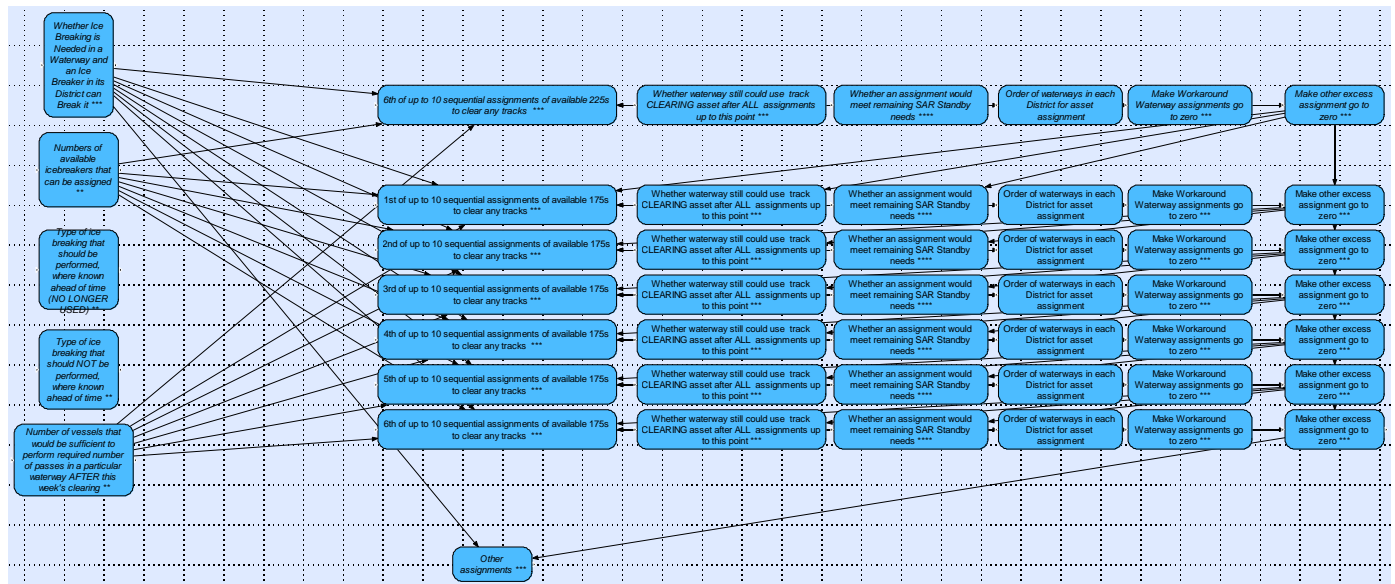


Figure 28. Assignment of any 175s to clear tracks.

The following five sub-sections will describe the key sub-modules of the “Assignment of Icebreakers to Waterways” sub-module that influence the allocation of ice breaking assets processed through the many sub-modules of the “Sequential Ice Breaker Assignments” sub-module discussed above. Specifically, the rules and conditions established by each of these main sub-modules determine the prioritization of ice breaking assets to waterways in which the assets are most needed. The “Sequential Ice Breaker Assignments” sub-module first considers advance assignments of icebreakers, and once these advance assignments have been met, the sub-module begins making assignments by cutter class and type of clearing activity based on inputs being simultaneously processed from the sub-modules discussed here.

4.3.4.1 Assignment of Icebreakers to Any Advance Assignments Sub-Module

Nested within the central “Sequential Icebreaker Assignments” sub-module is the “Assignment of Icebreakers to Any Advance Assignments” sub-module, shown in Figure 29. This sub-module assigns vessels to waterways according to advance assignments of icebreakers determined by SMEs. Advance assignments are made without considering factors that affect waterway priority in subsequent assignments, such as commercial vessel traffic, and are considered the first priority assignments each day. Several examples of these rules for advance assignments for District 1 include:

- On March 15 (Week 14), one 140' icebreaker is dispatched to the upper Hudson, also described as the Hudson River System, for preemptive flood control operations;
- From January 10 (Week 5) to February 15 (the end of Week 9), one 140' icebreaker is dispatched to clear ice in the lower Hudson River, also described as the Manhattan River System;
- From December 20 (Week 2) to February 28 (the end of Week 11), one 140' icebreaker is dispatched to clear ice in the upper Hudson River, also referred to as the Hudson River System; and
- On March 15 (Week 14), two 65' icebreakers are dispatched to the Kennebec and Penobscot Rivers for preemptive flood control operations.

For District 9, advanced assignment rules include:

- Assignment of a 240' to break out Upper Green Bay in Week 13.
- Assignment of a Canadian Icebreaker (1050 or 1100) to break out the Saint Lawrence River in Week 12.

Prior to making the assignments, the sub-module checks whether available inventories allow the advance assignments to be made. If applying all of the above rules for each day results in assignments that do not exceed the numbers of available icebreakers of a particular cutter class, then the sub-module proceeds to make all of the corresponding assignments. Otherwise, if only the weather-independent advance assignments can be made without exceeding available inventories, then the module makes only these assignments. If no advance assignments can be made due to limitations in availability of a particular type of icebreaker, then the module makes no advance assignments of that type of asset.

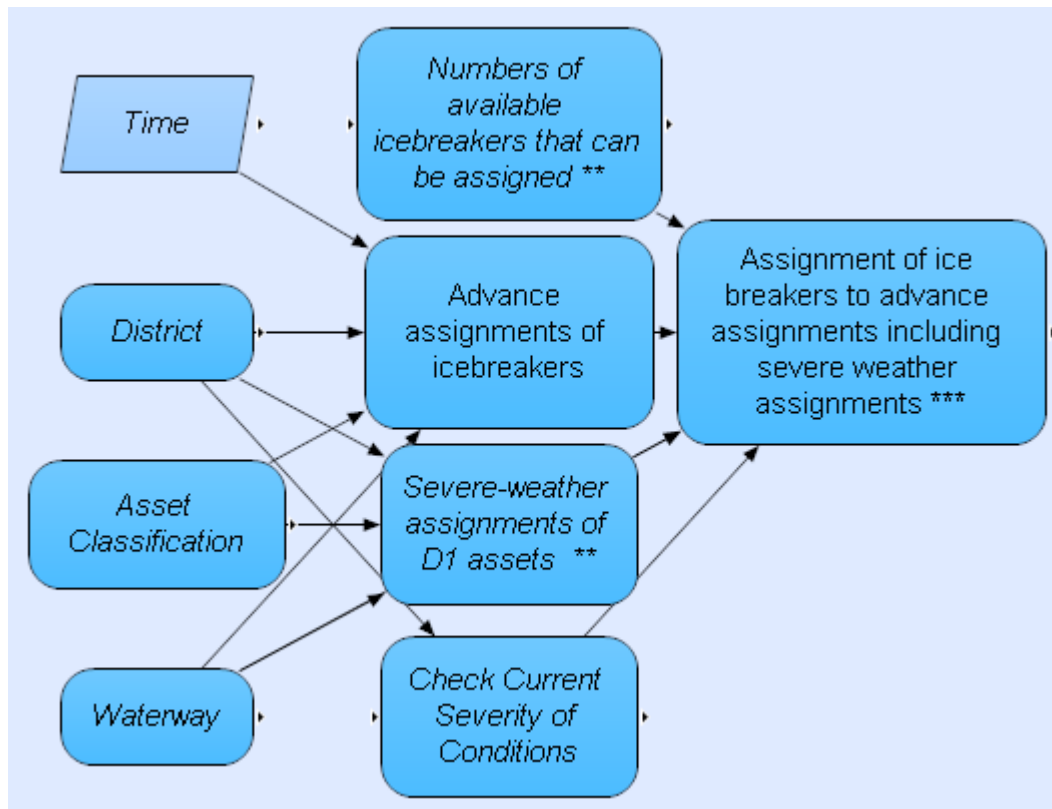


Figure 29. Assignment of icebreakers to any advance assignments sub-module.

4.3.4.2 SAR Standby Duty Requirements Sub-Module

Search and Rescue (SAR) standby duty requirements are considered in asset assignments by cutter class and type of clearing activity as one key factor in determining the priority of a waterway being assigned ice breaking resources. Figure 30 below demonstrates how SAR standby duty requirements are modeled for District 9. The modeled SAR standby requirement rules indicate, for each day and for each step in the assignment process, whether:

- Assets are subject to SAR Standby requirements that day; and whether
- There are not yet any assets assigned to each SAR Standby Area. There are five SAR Standby Areas in District 9, which include the Lake Superior Area, the Lake Huron Area, the Lake Michigan Area, the Lake Erie Area, and the Lake Ontario Area.

SAR standby duty requirements and the length of time dedicated to each SAR standby duty were determined according to the SAR Guard rules written in the "Cleveland SAR Plan"³ and the "Heavy Weather Plan." The following three statements from these documents are examples of the requirements to which the sub-module adheres:

- "From November 1st to April 1st, CGD Nine Waterways Management Branch (dpw-2) shall assign cutters to Lake SAR Standby for Lakes Erie, Huron, Michigan, and Superior;"
- "CGD Nine (dpw-2) will not normally SAR Standby for Lake Superior during the closed navigation season, nor for Lake Ontario;" and
- "CGD Nine may designate one cutter for multiple lakes, or 'dual hat'... Under normal circumstances, the total number of cutters assigned Lake SAR Standby in D9 shall not drop below three."

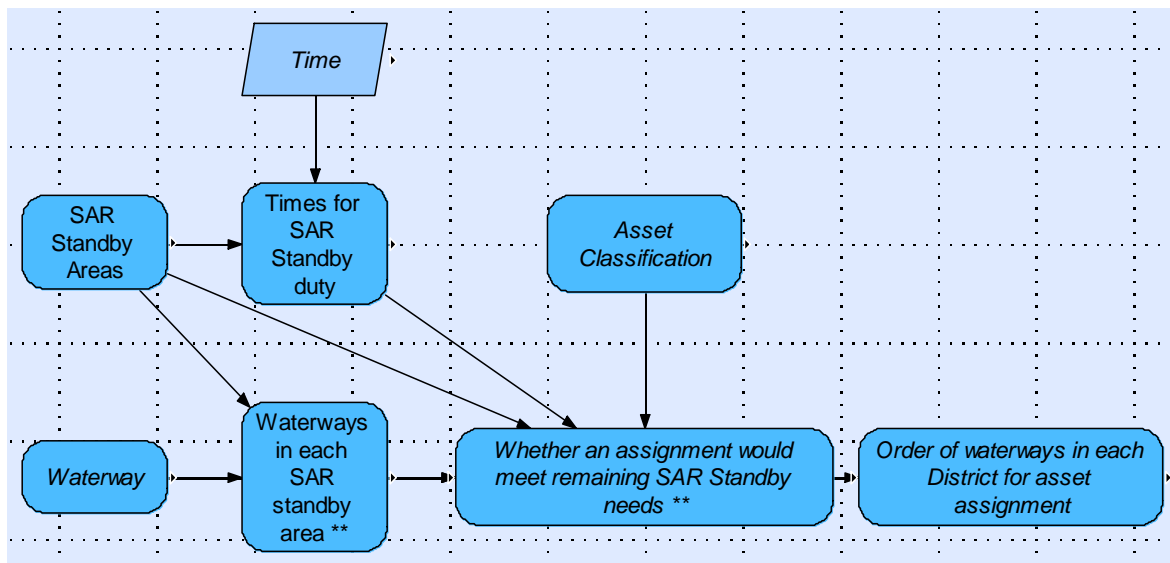


Figure 30. SAR standby duty requirements sub-module.

4.3.4.3 Time and Weather Dependent Rules on Types of Ice Breaking Sub-Module

Figure 31 below of the "Tables for Time- and Weather-Dependent Rules on Types of Ice Breaking" sub-module shows how time-dependent and weather-dependent rules are used to determine the type of ice breaking activity necessary in a waterway. For example, there are some periods of time that are known to only require icebreakers to perform indirect ice breaking, or maintenance runs, in District 1. There are also

³ USCG. Cleveland SAR Plan. CCGD9 INST M16100 (series).

time periods in which specific waterways are allowed to ice over in District 9, such as part of Green Bay during the closed navigation period. Assets are assigned to waterways using these criteria only if advance assignments have been fulfilled and available assets remain after fulfilling SAR standby duty requirements. In addition, version 2.0 of the model includes a variable that restricts the deployment of particular asset classes to particular waterways. This prevents the deployment of asset classes that are incapable of being assigned to a particular waterway. For example, this prevents the assignment of 65s to the Cape Cod Canal.

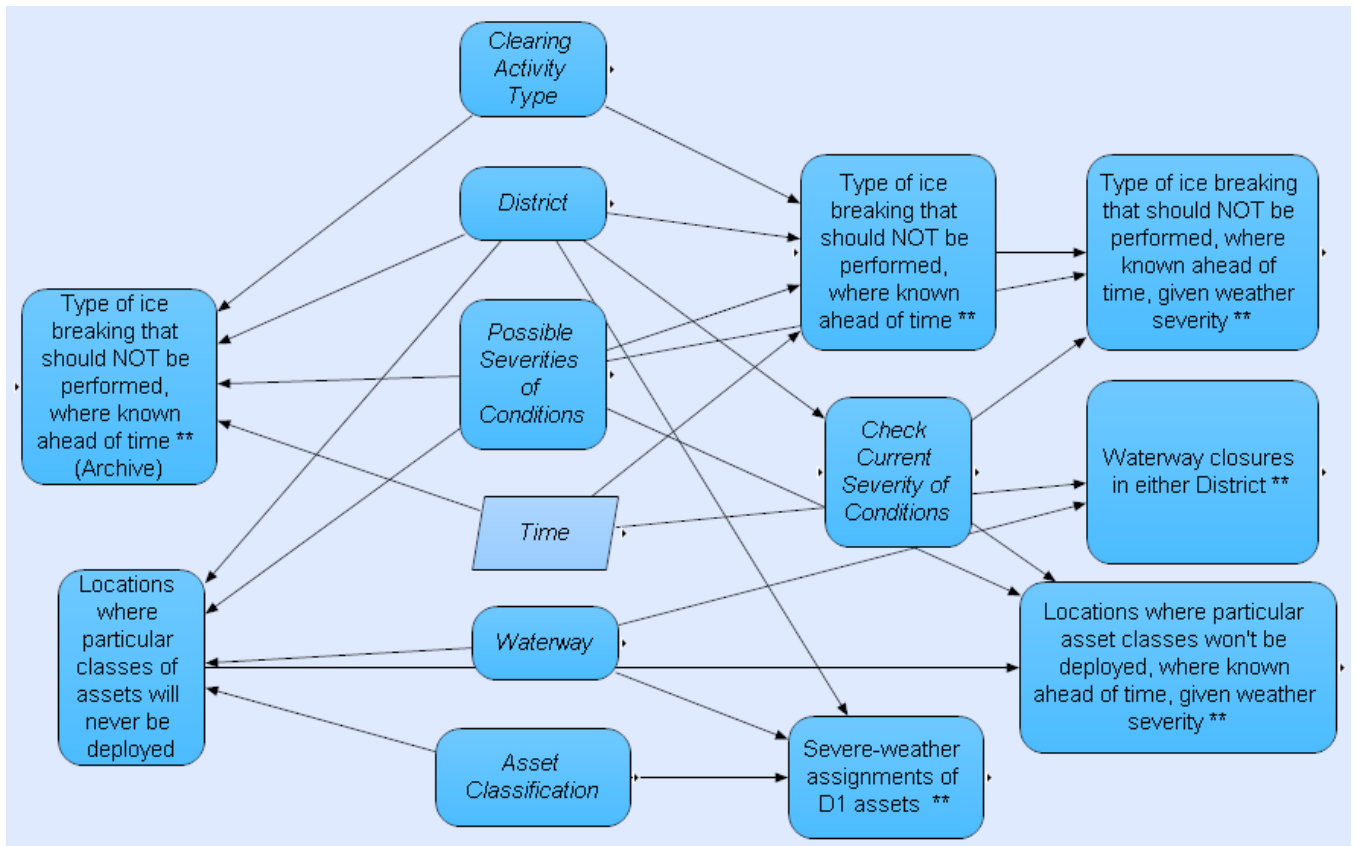


Figure 31. Tables for time- and weather-dependent rules on types of ice breaking sub-module.

4.3.4.4 Waterway Priority for Asset Assignment Sub-Module

Figure 32 below shows the “Waterway Priority for Asset Assignment” sub-module that contributes to the prioritization of waterways in each District based on their priority for asset assignment. This sub-module processes AIS vessel traffic data to indicate the relative commercial importance of waterways within a District. Waterways are prioritized based on the number of commercial vessels transiting the waterway. In other words, for each day, the waterway that is transited by the most commercial vessels is considered the waterway with the highest priority for ice breaking activities. In addition, the sub-module contains a table with manual weights for waterway prioritization as well. This allows for additional weighting to be given to particular waterway/asset classification pairings. Prioritization of the waterways is determined for the set of waterways that meet all of the above conditions and that do not yet have an appropriate icebreaker assigned. As Figure 32 indicates, SAR standby duty requirements are also considered in this sub-module as a checking mechanism to determine if a vessel assignment may also satisfy remaining SAR standby duty needs.

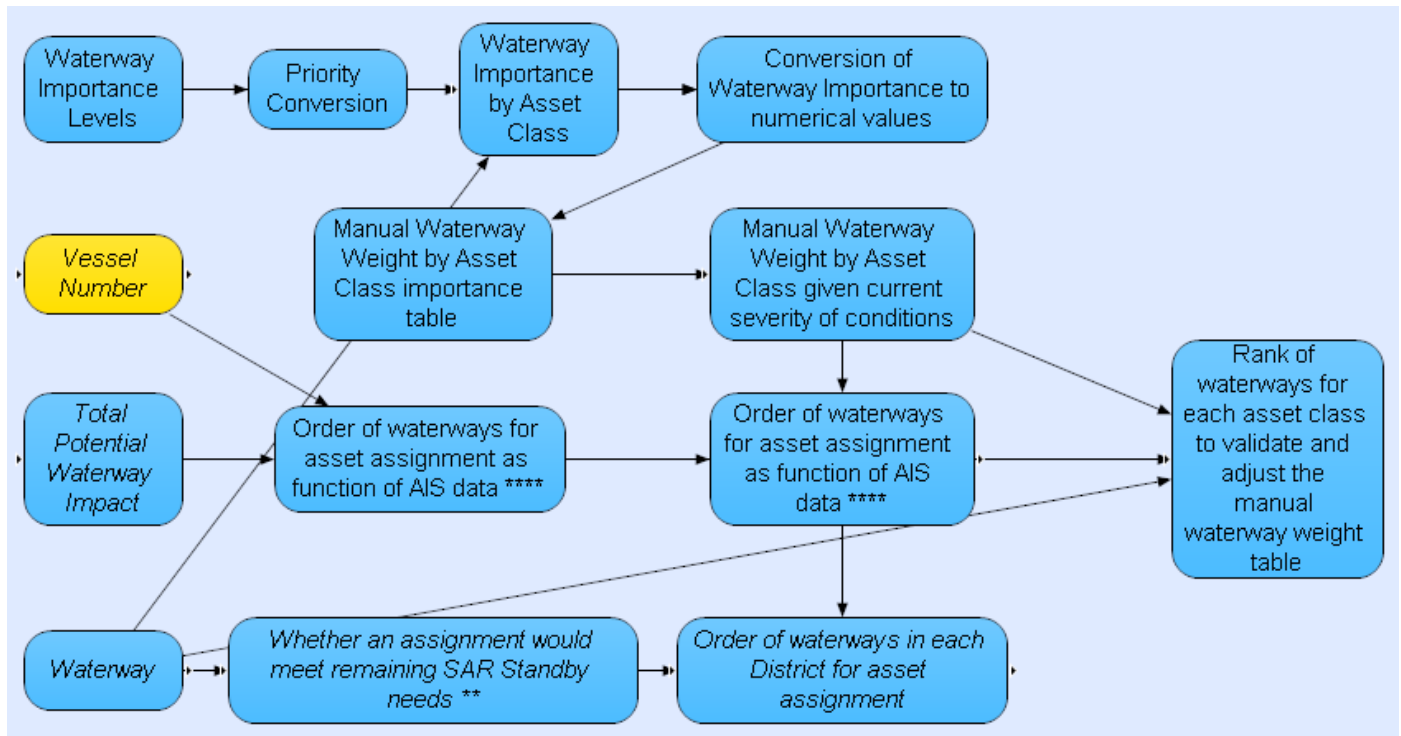


Figure 32. Waterway priority for asset assignment sub-module.

4.3.4.5 Other Factors Considered During Icebreaker Assignment Sub-Module

Figure 33 of the “Other Factors Considered During Icebreaker Assignment” sub-module demonstrates that there are several variables that define basic operational factors that influence the assignment of ice breaking assets. Many of these factors are used to determine the number of vessels necessary to perform the required number of passes per day in a particular waterway, which depends on:

- The speeds at which vessels perform either track maintenance or direct/active clearing, as well as the requisite number of passes for track maintenance or direct/active clearing;
- The number of daylight hours;
- Transit times, if applicable; and
- Whether assigned icebreakers were sufficient to perform continuous track maintenance in the waterway the previous day or whether the ice has been cleared at least once in the current day.

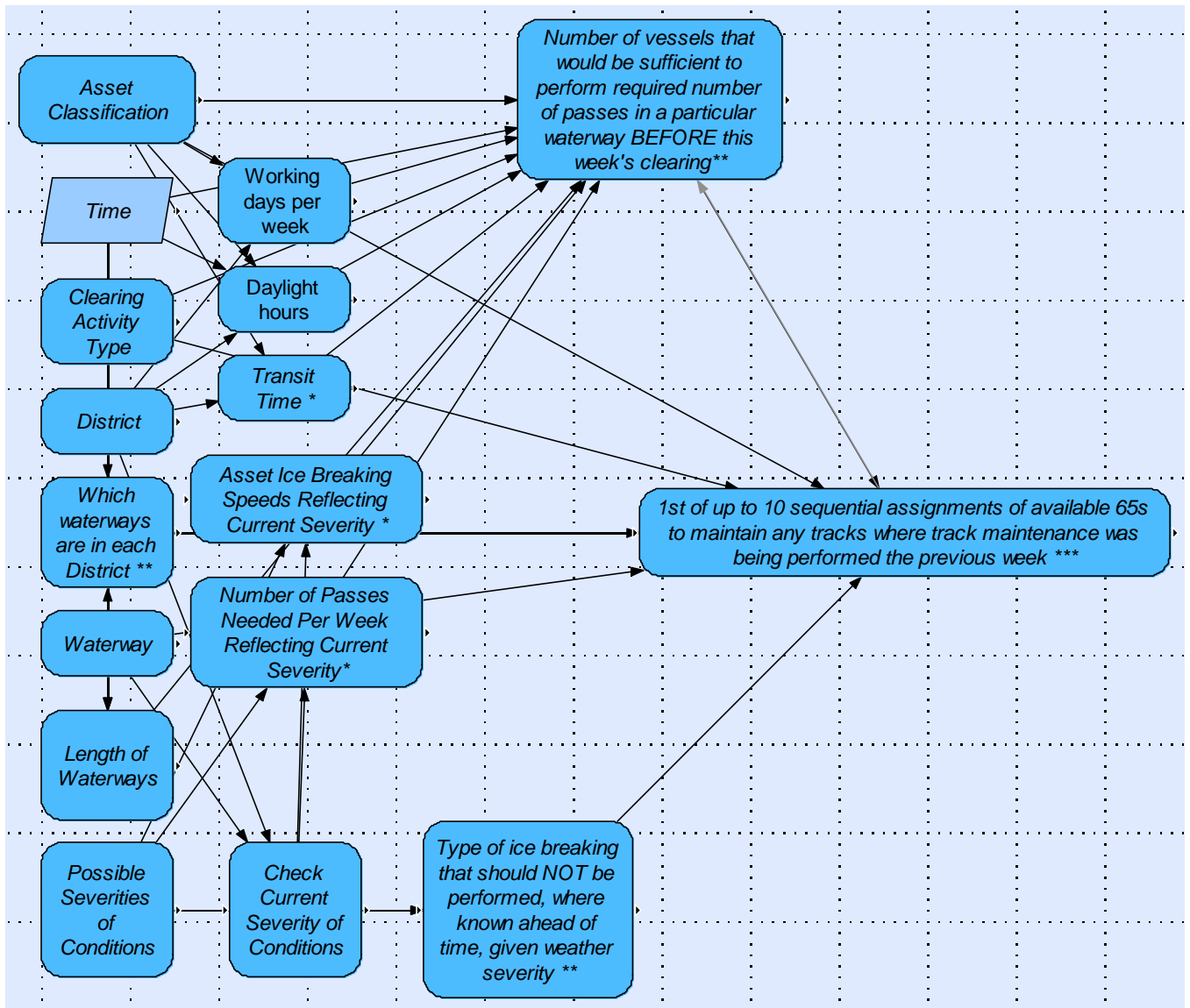


Figure 33. Other factors considered during ice breaker assignment sub-module.

4.3.4.6 Outputs of the “Sequential Icebreaker Assignments” Sub-Module

The final output of the “Sequential Icebreaker Assignments” sub-module, and therefore the output of the entire “Assignment of Icebreakers to Waterways” sub-module, is the number of assets of each cutter class assigned to each waterway for each day in each District. Figure 34 shows the outputs of the assignment process. As a means of confirming that the resulting number of icebreakers assigned is reasonable, the sub-module compares the total number of assets assigned to the total number of assets available for assignment. If the number of assets assigned does not exceed the total number of available assets for assignment, the sub-module’s results are validated.

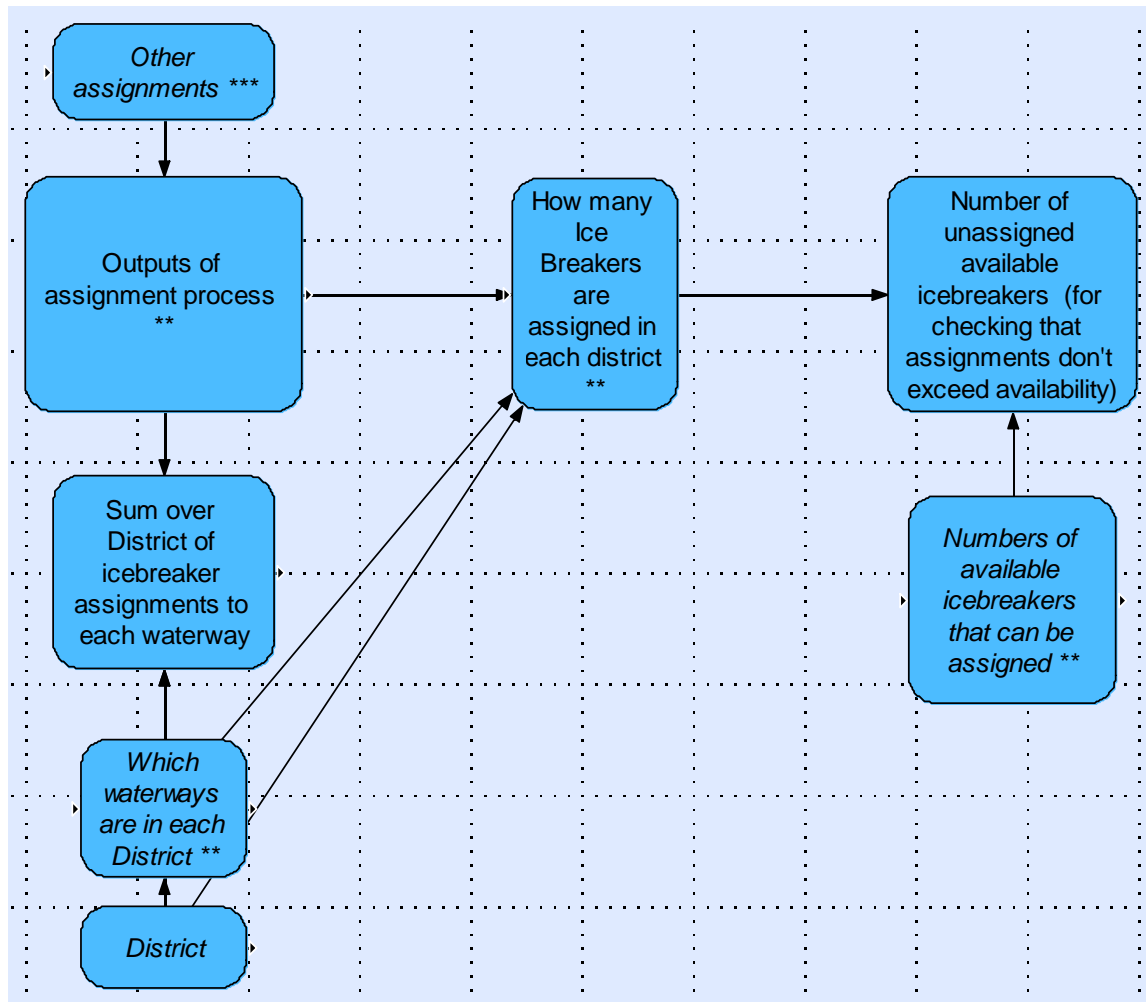


Figure 34. Outputs of assignment process.

4.4 Economic Impact Module

The outputs from the “Ice Breaking Demand” and “Ice Breaking Supply” modules are used to determine the length of time a waterway would remain closed to vessel traffic as a result of the demand for ice breaking activities being unmet by the supply of available ice breaking assets. The “Economic Impact” module, referred to as the “DOMICE Economic Impact” module in the *Analytica*® model, calculates the economic impact of the waterway closures that occur in an ice breaking season due to this unmet demand. Economic impact is calculated based on two main types of impacts, namely, cargo shipping impacts and flooding impacts. The module’s output is the total economic impact of waterway closures for the entire season, which reflects the risk associated with DOMICE activities.

Figure 35 of the “DOMICE Economic Impact” module demonstrates the different sub-modules involved in calculating the total economic impact of waterway closure.

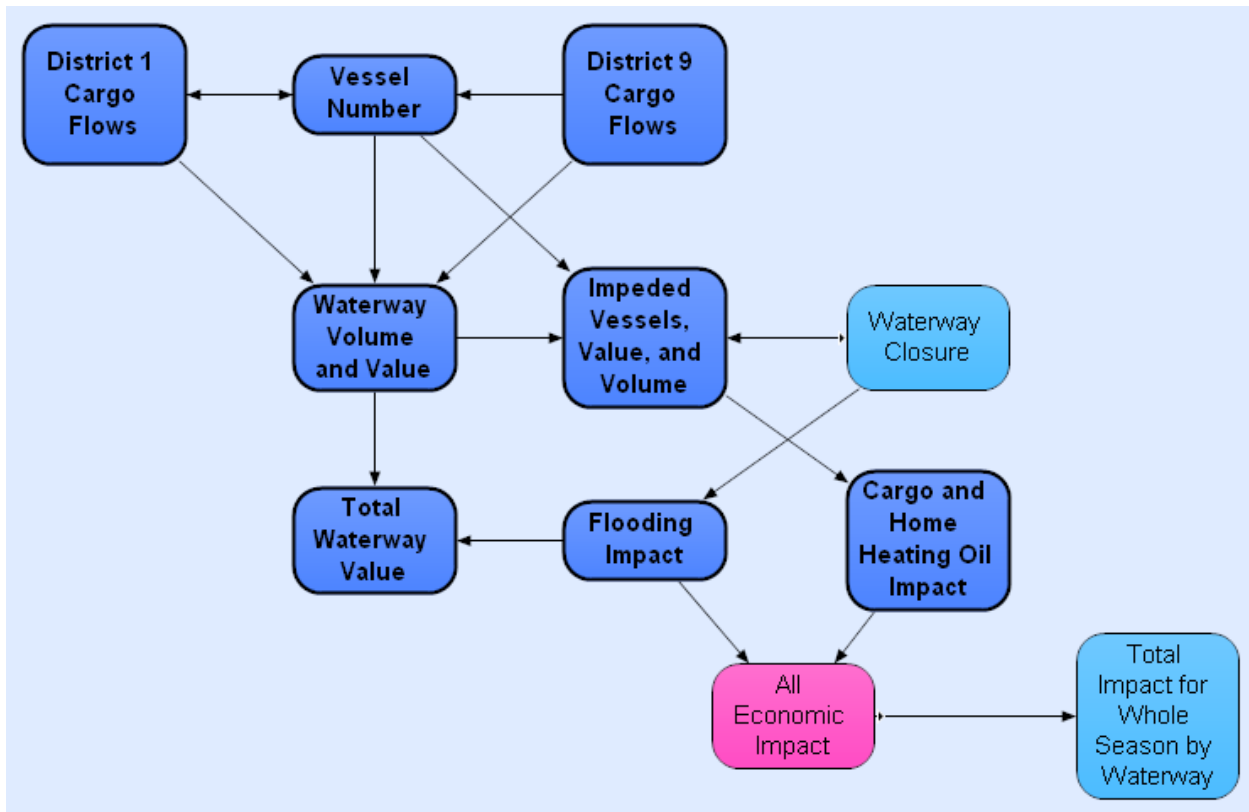


Figure 35. DOMICE economic impact module.

4.4.1 Cargo Flow

The “Economic Impact” module contains sub-modules that determine from historical data the average cargo volume transported per vessel during the winter navigation season in District 1 and in District 9. Three data inputs are used to determine these values: historical AIS data indicating vessel traffic flows; data on cargo volumes transported on each waterway provided by USACE’s Waterborne Commerce Statistics Center (WCSC) and the Lake Carriers’ Association (LCA); and economic values of cargo transported, obtained from the US Economic Census. The following cargo types are considered in the module: dry bulk goods; liquid bulk goods; perishable goods or food; and home heating oil. These four types of cargo are further grouped into two broader categories, namely, Home Heating Oil (HHO) shipments or Non-HHO shipments.

The data from the USACE and LCA are used to determine the average amount of each type of cargo, in metric tons, transported on each waterway for each day of the winter navigation season. Average cargo volumes are divided by the estimated number of vessels transiting each waterway during each day of the ice breaking season to determine the average cargo volume transported per vessel. Distinctions between vessel types and sizes are not included in the analysis. AIS data is used to determine the number of vessels carrying each type of good on each waterway per day, which is the output of the “Vessel Number” sub-module shown below in Figure 36. The sub-module contains an archive of the original weekly data from version 1.0.

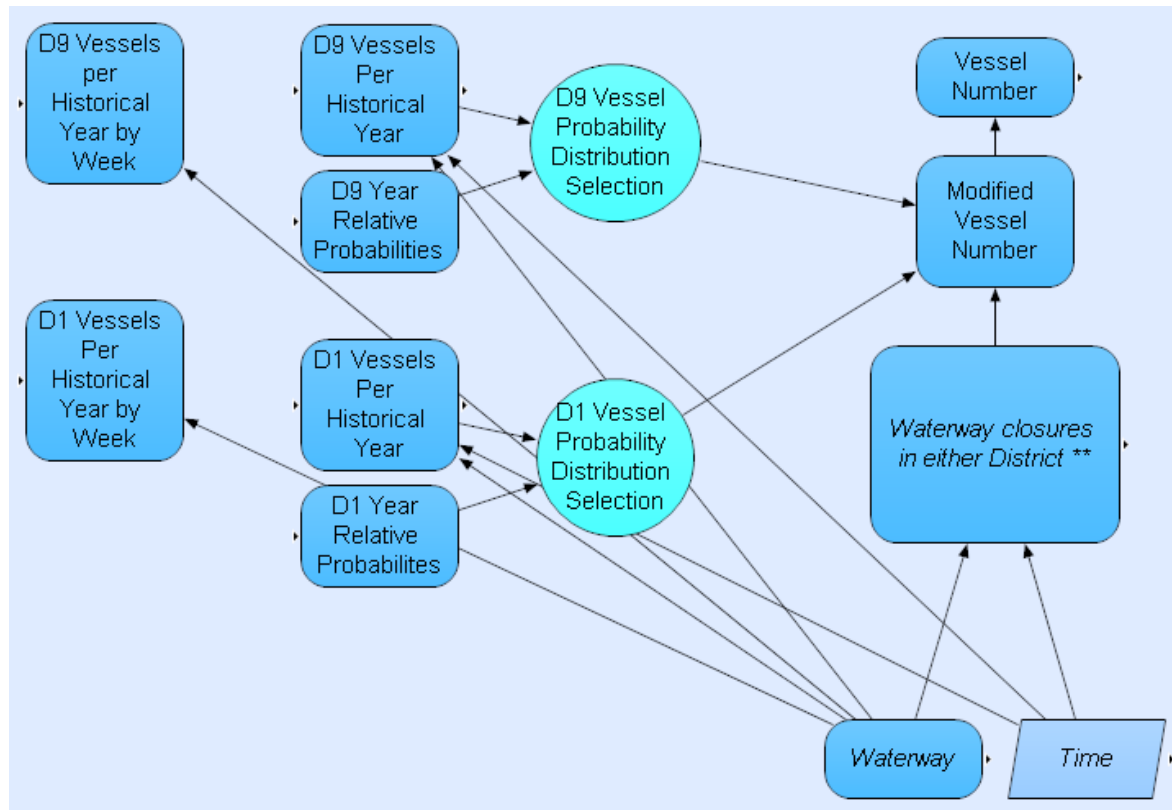


Figure 36. Vessel number sub-module.

Figures 37 and 38 below show how LCA and USACE data are processed for each District in separate sub-modules to determine the expected level of cargo per vessel for the entire District, by cargo type.

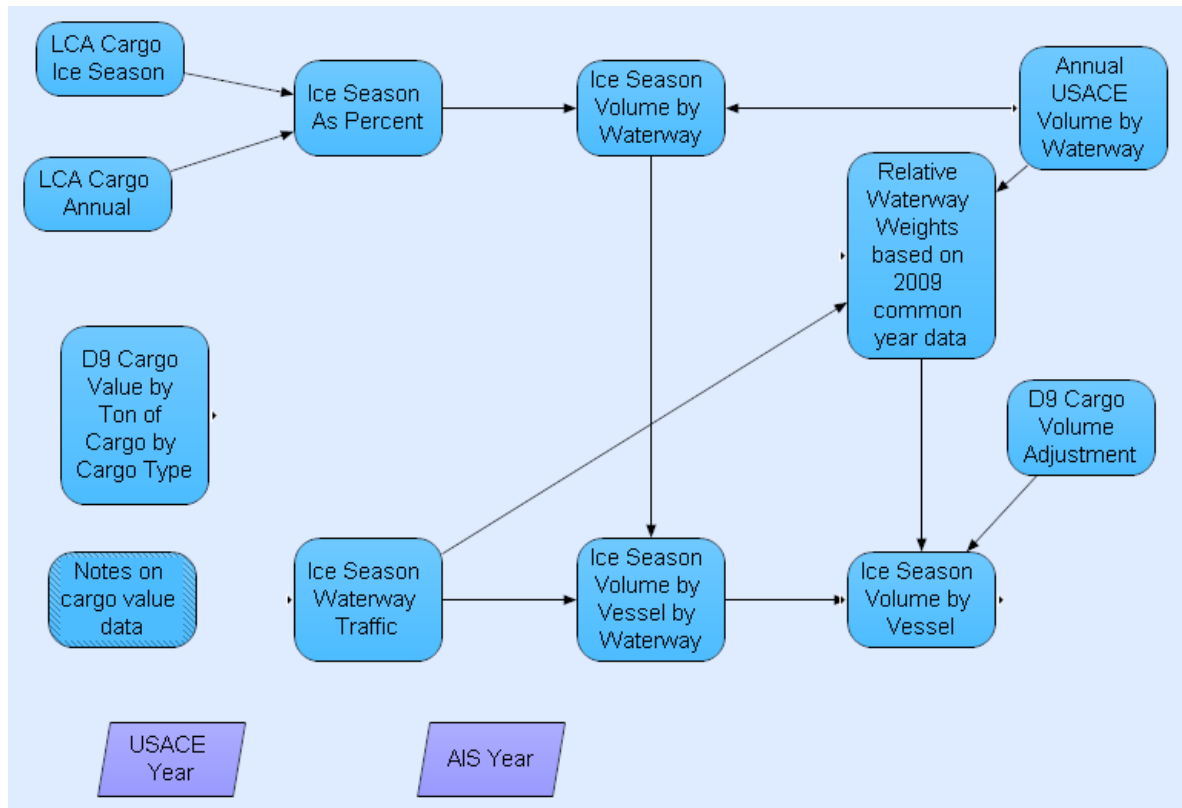


Figure 37. Vessel number sub-module.

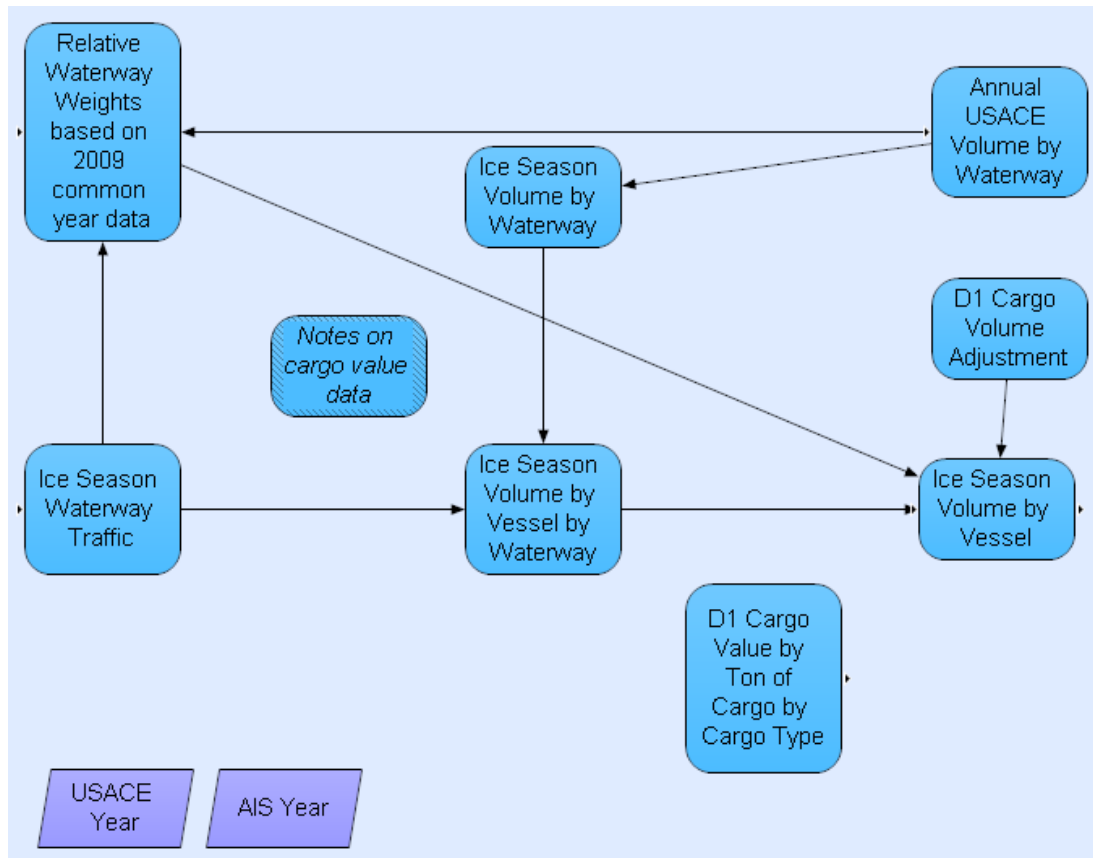


Figure 38. District 1 cargo flows sub-module.

4.4.2 Calculation of Economic Impact of Waterway Closure

Once the assignment of ice breaking assets to waterways has been made by the “Ice Breaking Supply” module for each day in each District, a “Waterway Closure” table is generated in the “Economic Impact” module that indicates which of the Tier 1 and Tier 2 waterways are closed for that day in each District. In the “Waterway Closure” table generated, waterways that are open are indicated with an entry of “0” and waterways that are closed are indicated with an entry of “1.” Waterways are closed if either the thickness of ice on the waterway could not be broken by the assets available, or if there were not enough ice breaking assets to be assigned to that waterway for the day.

The “Economic Impact” module monetizes the impacts caused by waterway closures each day based on impacts related to cargo impedance and impacts related to flooding incidents. The following two sub-sections will discuss how each of these impacts is measured.

4.4.2.1 Cargo Impedance Impact Calculations

Figure 39 shows the “Waterway Volume and Value” sub-module located within the “DOMICE Economic Impact” module. This sub-module uses the outputs of the “District 9 Cargo Flows” and “District 1 Cargo Flows” sub-modules, which are the average cargo volumes per vessel in each District, to determine the total cargo volume transported on each waterway. The sub-module then uses US Economic Census data to calculate the economic value of the cargo transported on each waterway for every day of the winter

navigation season. The value of cargo transported is used as an input to determine the final downstream impacts of waterway closures to consumers. Additionally, the value of cargo transported is used to determine the criticality of each waterway, which in turn feeds into the “Ice Breaking Demand” and “Ice Breaking Supply” modules. The “Total Waterway Value” sub-module shown in Figure 40 determines waterway criticality by calculating the total economic value of cargo on waterways and potential impacts from waterway closure. This value of total potential waterway impact is used to break ties in asset assignments between waterways that are otherwise of equal priority for ice breaking resources. It should be noted that while the “Economic Impact” module contributes to determining waterway criticality, waterway criticality is not involved in the calculation of the total economic impact of waterway closures. The determination of waterway criticality based on the commercial importance of each waterway is used exclusively in determining the demand for ice breaking activities and prioritizing the allocation of ice breaking assets to the waterways that have greater ice breaking demand.

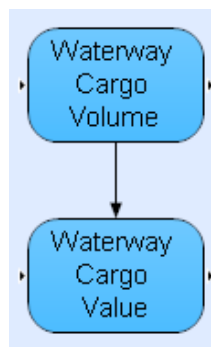


Figure 39. Waterway volume and value sub-module.

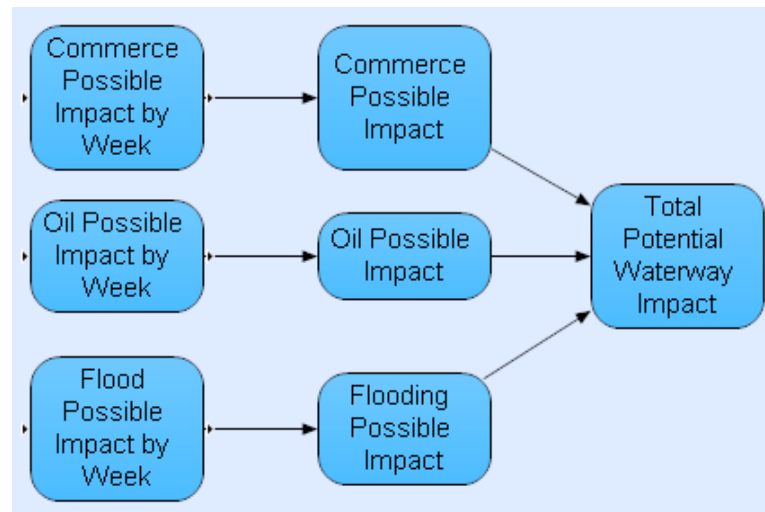


Figure 40. Total waterway value.

The “Impeded Vessels, Value, and Volume” sub-module, shown in Figure 41, and its sub-module, “Cumulative Volume Impeded” shown in Figure 42, determine the cumulative cargo volume impeded for the entire ice season according to the waterway closures incurred throughout the season.

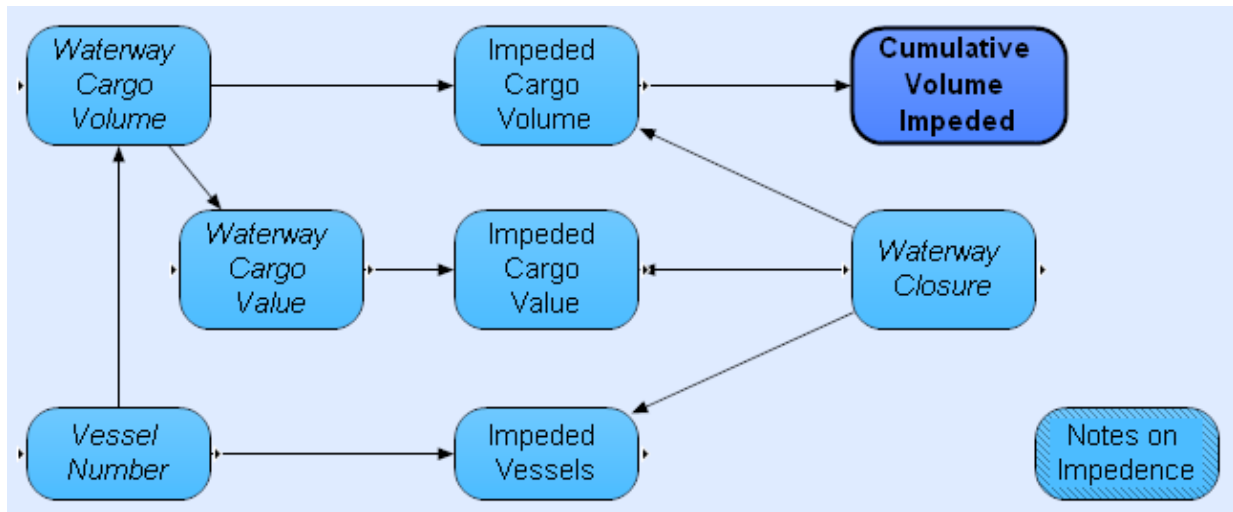


Figure 41. Impeded vessels, value, and volume sub-module.

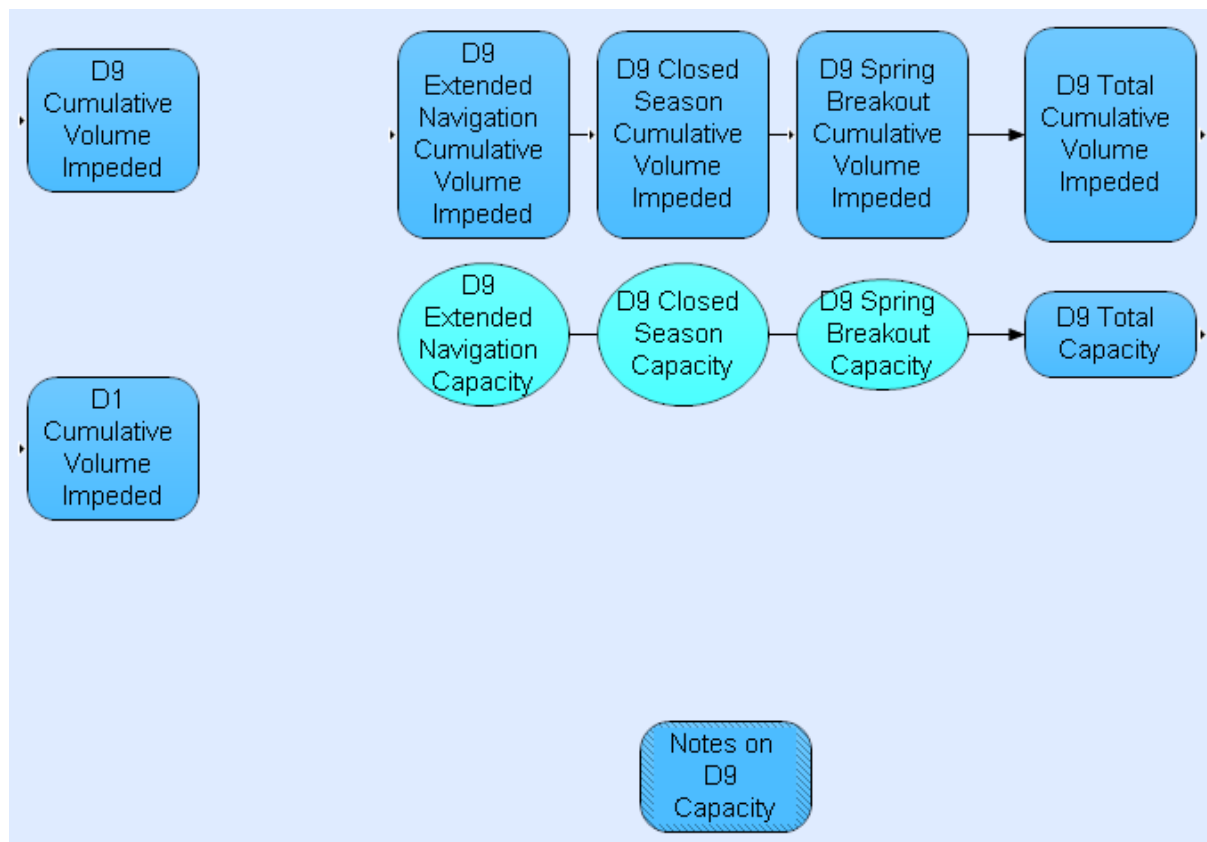


Figure 42. Cumulative volume impeded sub-module.

The “Cargo and Home Heating Oil Impact” sub-module calculates the costs incurred from delayed or displaced cargo shipments caused by waterway closures. As Figure 43 below of the sub-module demonstrates, three main types of costs are considered, namely: alternative shipping impacts; operating costs; and downstream impacts on consumers.

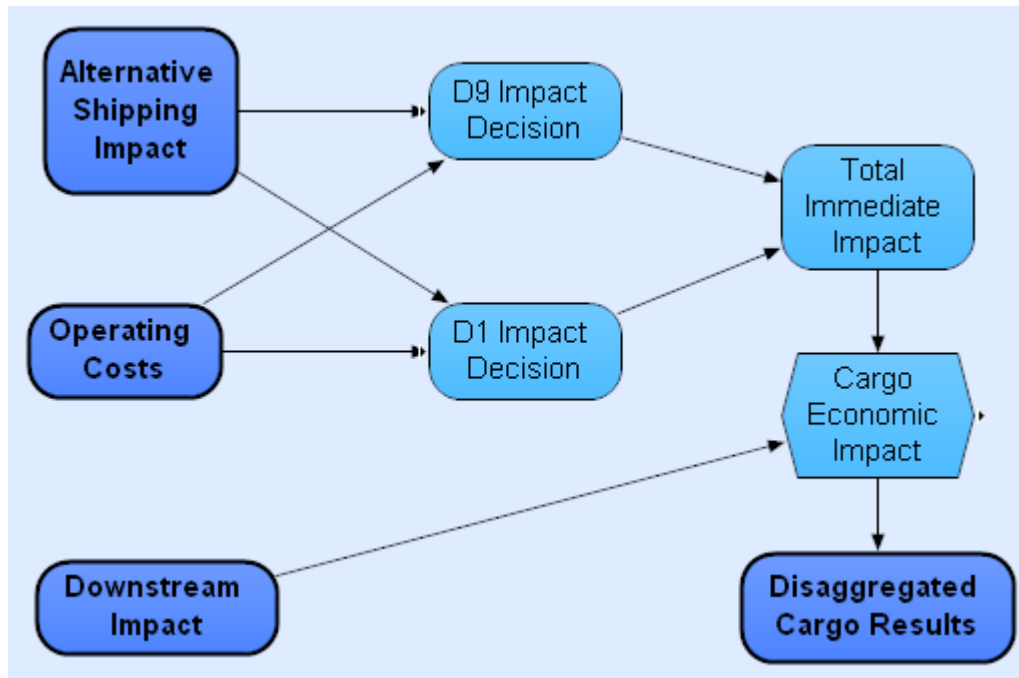


Figure 43. Cargo and home heating oil impact sub-module.

An assumption of the sub-module is that a shipment of cargo impeded by a closed waterway will either be delayed until the waterway is re-opened before proceeding to its final destination, or the cargo will be re-routed to an alternative mode of transportation, such as highway transport. In the first case, cargo vessels still have the capacity to transport the amount of shipment delayed, whereas in the second case, vessel capacity is exceeded by the quantity of delayed shipments, causing these shipments to be shipped by alternative modes of transportation. Both options incur unique costs. The sub-module either assigns “Operating Costs” or “Alternative Shipping Costs” to an impeded shipment. Operating cost impacts include the cost incurred by vessel owners or operators while waiting for the waterway to be reopened. Alternative shipping costs considers the increased cost of offloading goods at an intermodal port and loading them onto overland transportation means.

Due to the greater availability of commercial vessels and lack of distinct navigation seasons in District 1, all commercial cargo, except home heating oil, is assumed to be delayed while waiting for the waterway to reopen. Due to the critical nature of home heating oil, all home heating oil is rerouted to overland transportation, specifically by truck, for distribution to the surrounding area.⁴

District 9 experiences a much greater constraint than District 1 due to the relatively fixed size of the fleet of commercial vessels operating in the lakes, known as “Lakers,” during an ice season. Initially, cargo is assumed to be delayed and costs are borne by the vessel owners or operators. Once the cumulative level of impeded cargo exceeds the spare capacity of the Laker fleet, the model reroutes the cargo to overland routes and assigns costs associated with the increased cost of overland transport.

⁴ In an acute period of shortage, the heating oil distribution network may not have the capacity to deliver all required heating oil without incurring additional operating costs or experiencing degradation in service to other areas.

Figures 44 and 45 indicate how operating costs and alternative shipping costs are calculated through the “Operating Costs” sub-module and the “Alternative Shipping Impact” sub-module.

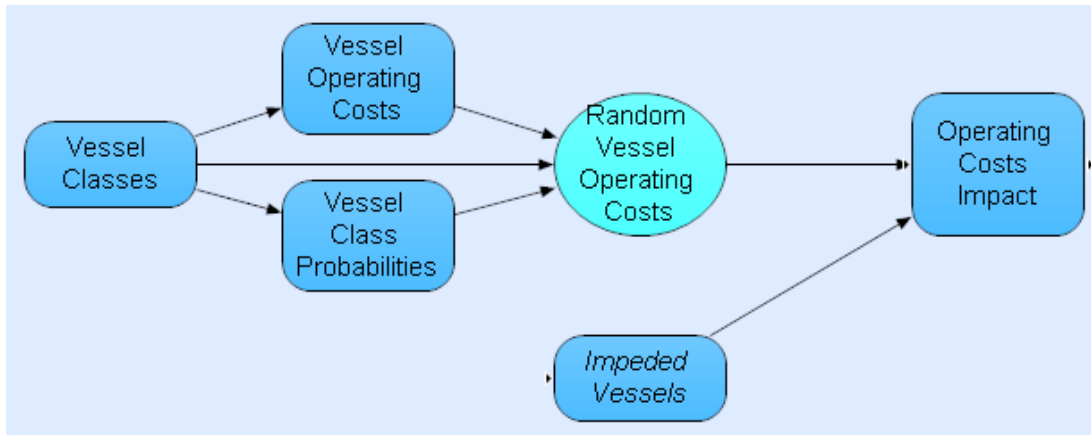


Figure 44. Operating costs sub-module.

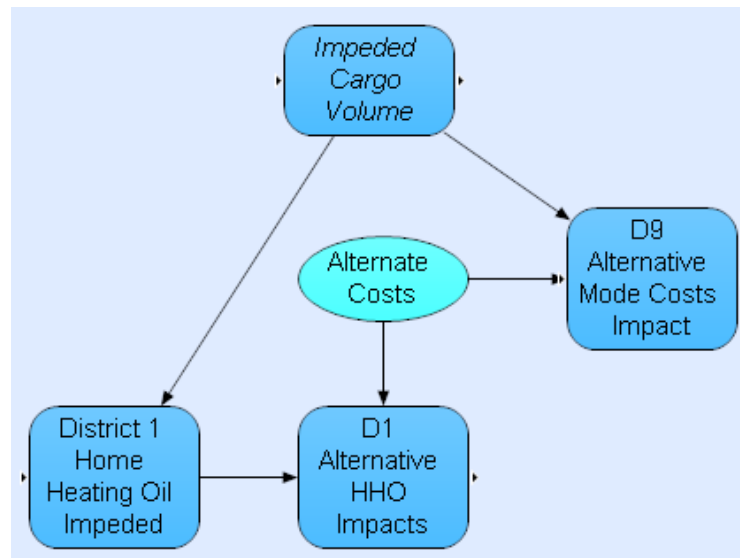


Figure 45. Alternative shipping impact sub-module.

In addition to the immediate expenses faced by vessel owners, operators, or transportation firms, the delay in cargo shipments has an impact on the downstream consumers of the goods being transported. The actual impact could vary among individual consumers based on the specific good delayed, the length of the delay, and the supply chain resiliency, however, this extent of detailed information was unavailable from existing data sources. Based on current studies⁵ of the economic impact of cargo delays, a range of costs to downstream consumers was selected for each type of cargo. In District 9, the level of the impact is also driven by the sub-season. Figure 46 demonstrates how downstream impacts are calculated in the “Downstream Impacts” sub-module.

⁵ Martonosi, Susan E., David S. Ortiz, and Henry H. Willis. Evaluating the Viability of 100 Per Cent Container Inspection at America’s Ports. Santa Monica, CA: RAND Corporation, 2005. <http://www.rand.org/pubs/reprints/RP1220>.

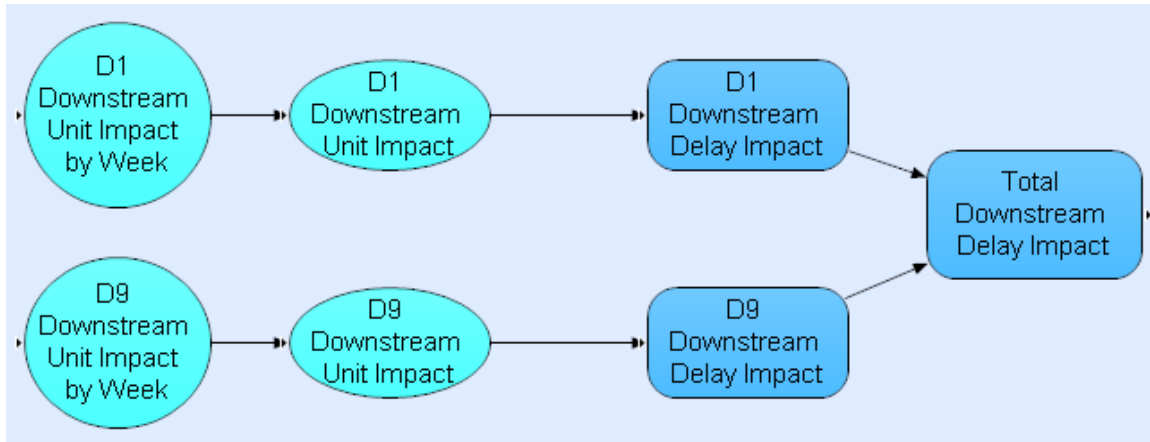


Figure 46. Downstream impacts sub-module.

The outputs of the “Cargo and Home Heating Oil Impact” sub-module are the total cargo impacts caused by waterways closures, and are compiled in the “Disaggregated Cargo Results” sub-module shown in Figure 47.

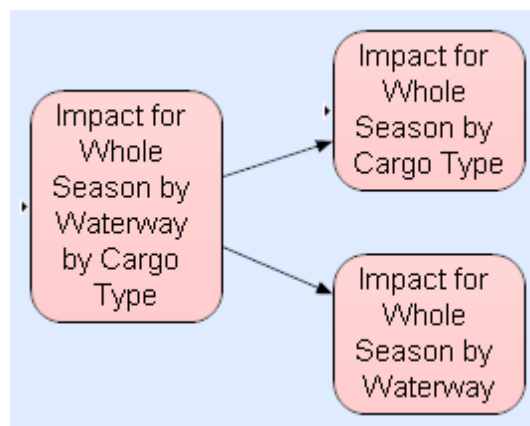


Figure 47. Disaggregated cargo results sub-module.

4.4.2.2 Flooding Impacts Calculations

The “Flooding Impact” sub-module, shown in Figure 48, calculates the expected flooding impacts in each waterway, given the waterway closures simulated by the model. Consequences of flooding events are based primarily on the estimated impacts of analogous historical incidents⁶. Based on historical data available from the NOAA National Climactic Data Center (NCDC), the probability of ice induced flooding occurring in waterways along the coast of Maine was determined for each week in the ice season. The impact of flooding was similarly simulated based on the historical impact of flooding in each of the waterways identified. Figure 46 shows how probabilistic estimates of flooding impacts incorporate probabilities of flood occurrence when waterways becomes closed in order to estimate the impacts that would result from a flood. Figure 49 of the “Flooding Impact by Waterway” sub-module indicates the data used to estimate the impacts that would result from a flood.

⁶ USACE (2002). Engineering and Design: Ice Engineering. Manual 1110-2-1612. Washington, DC, U.S. Army Corps of Engineers.

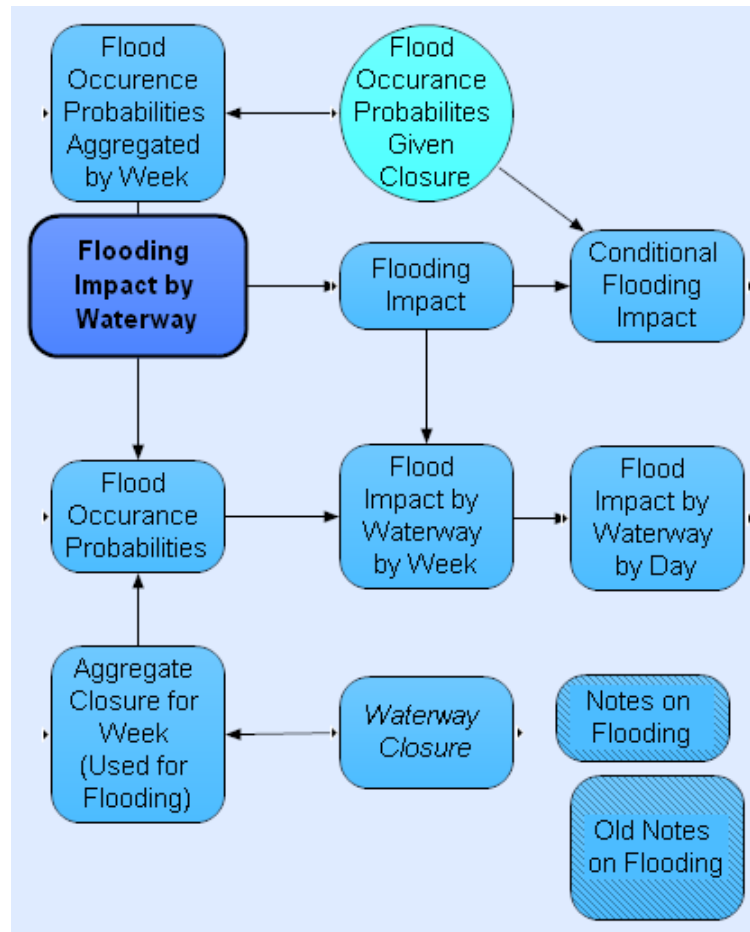


Figure 48. Flooding impact sub-module.

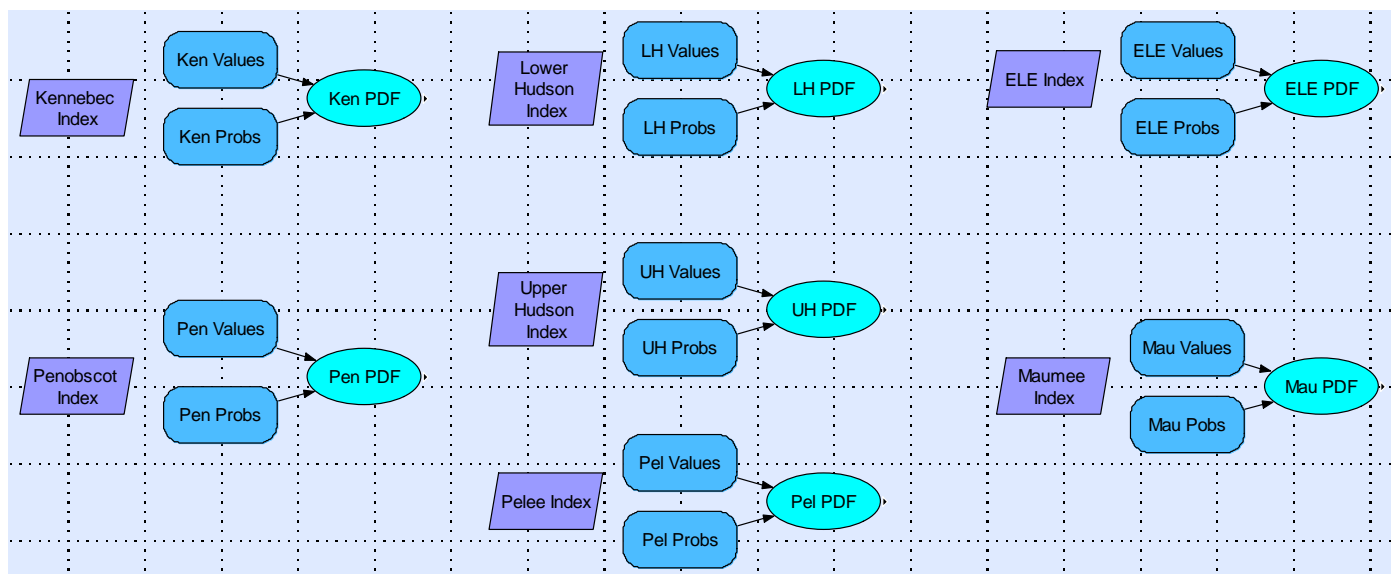


Figure 49. Flooding impact by waterway sub-module.

4.5 DOMICE Outcomes

The primary DOMICE simulation outcomes, as shown below in Figure 50 of the “DOMICE Outcomes” module, include the total economic impact of waterway closures for each District over the entire winter navigation season associated with specific icebreaker allocations.

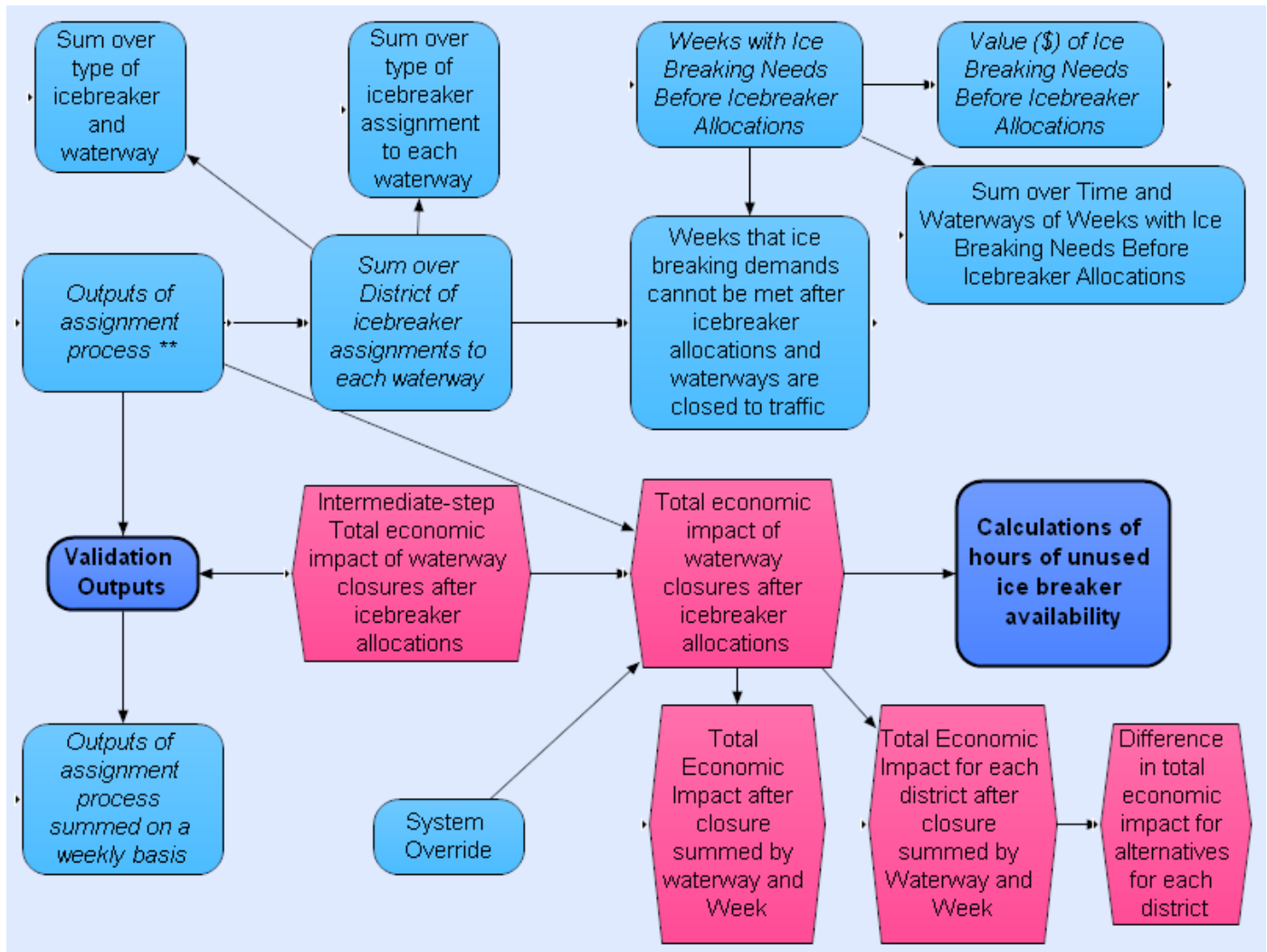


Figure 50. DOMICE outcomes.

Additional simulation outcome calculations assess the effect of the modeling approximation that assets are assigned to a single waterway or waterway system for an entire day. This effect is assessed by calculating the number of unused hours of assigned icebreakers, or the number of hours that assigned icebreakers would have available in a day beyond what is needed to keep their assigned waterways clear. If the icebreaker has a sufficient number of hours available to maintain a nearby waterway, the model eliminates the risk of the second waterway. Figure 51 demonstrates how this calculation is performed, in the “Calculations of Hours of Unused Icebreaker Availability” sub-module.

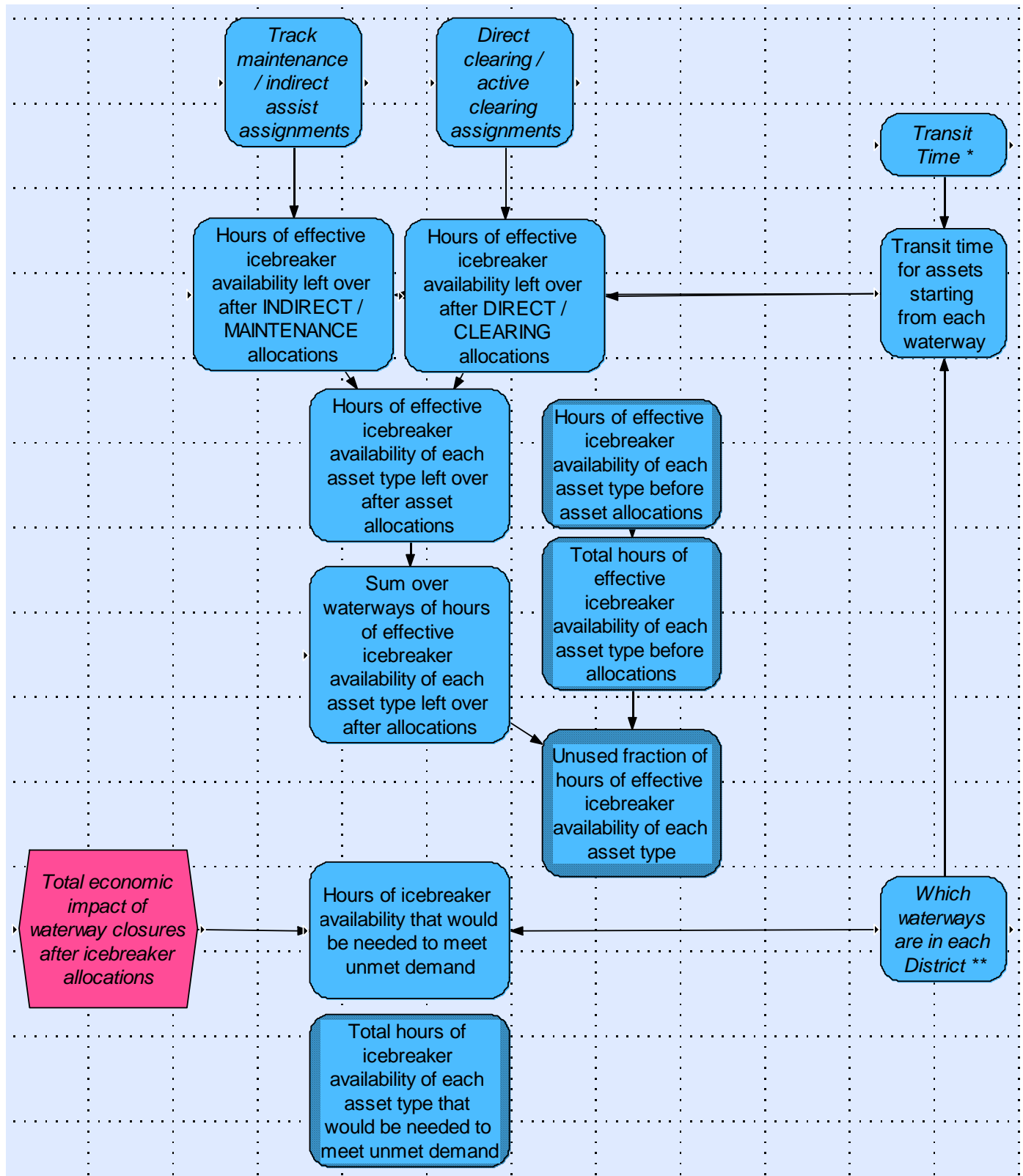


Figure 51. Calculations of hours of unused icebreaker availability.



4.6 Model Sensitivity

Sensitivity analysis explores and quantifies the extent to which the values of the model's output variables are sensitive to, or depend, changes in values of the model's input variables. Similarly, uncertainty importance analysis explores and quantifies the extent to which uncertainties in the values of the model's output variables are sensitive to, or depend, uncertainties in values of the model's input variables. Because of the complexity of the DOMICE Analytica® model and the indexed nature of many of its inputs, some of the more common sensitivity analysis and uncertainty analysis techniques (including tornado plots and uncertainty importance analysis using rank-order correlation) are not straightforward to sensibly implement for all of the model's major uncertain variables. Instead, Figure 52 presents results of an analysis of the model's sensitivity to selection of ice/weather data year using linear regression.

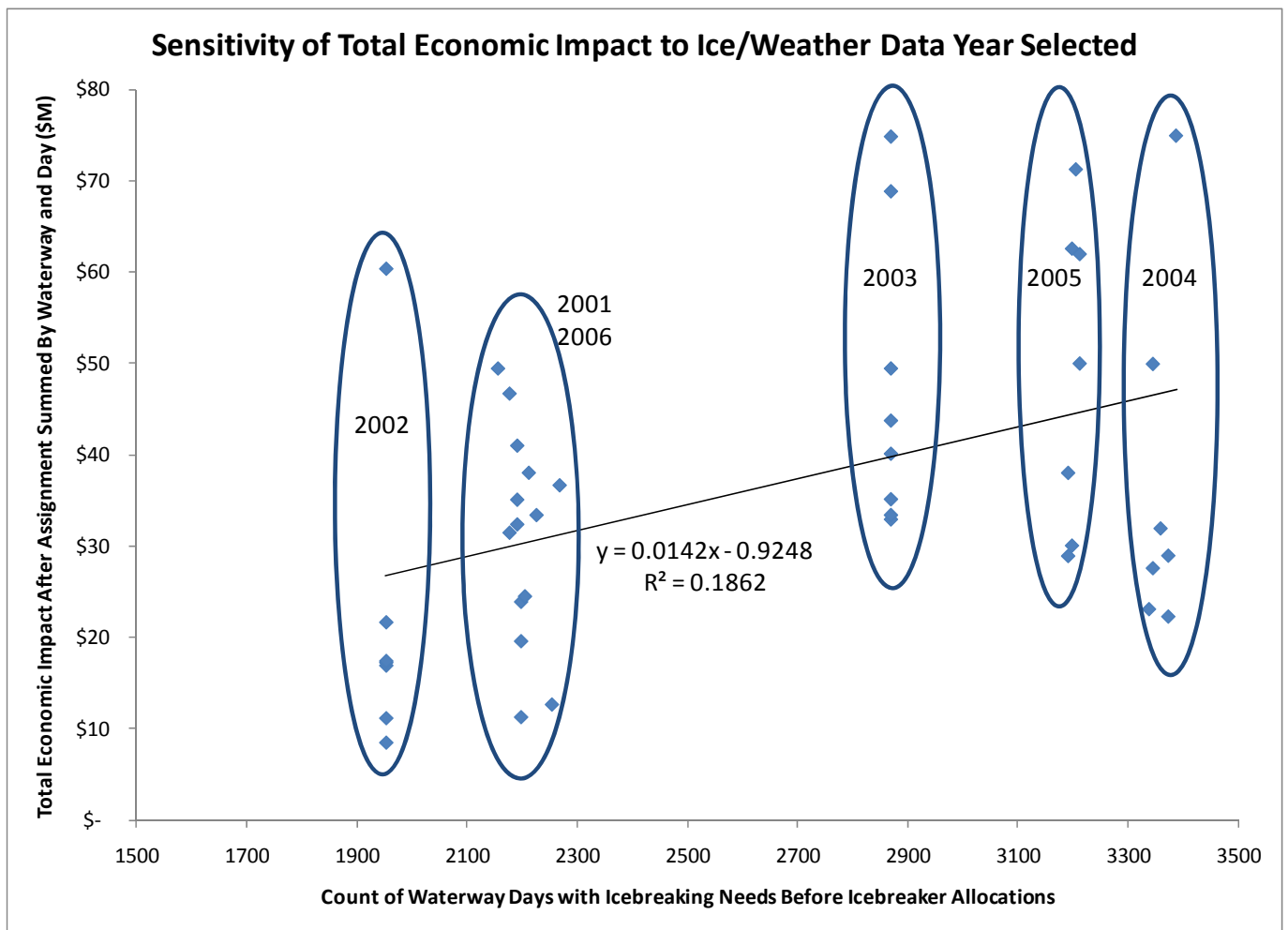


Figure 52. Model sensitivity.

Excluding data from the 1999 year, each data point represents the results of one Monte Carlo iteration out of a total of 50 iterations. The vertical axis is Total Economic Impact after Closure Summed by Waterway and Week, which is a major output of the model. The horizontal axis the Count of Waterway-Weeks with Ice Breaking Needs Before Icebreaker Allocations, which is one way to quantify the extent of the direct effects of ice in the model. The data points also have grouped labels of the Ice/Weather Data Year. Finally, the

figure includes a simple linear regression line, equation, and the R squared coefficient of determination. The R squared value is a measure of how well the regression fits the points (where R squared can range from 0 to 1 and a value of 1 indicates a perfect fit). The regression has an R squared value of 0.19, which indicates that variation in the count of waterway-weeks with ice breaking needs can explain approximately 19% percent of the variation in total economic impact.

Although the direct correlation between year and economic impact has decreased in model version 2.0, simple visual inspection of the groupings of data points indicates that the weather/ice data year is a strong determinant of count of waterway-weeks with ice breaking needs. The 2003 winter, which was separately identified as a severe winter, has some of the highest economic impact and the second-highest count of waterway-weeks with ice breaking needs. Although 2004 had more waterway-weeks with ice breaking needs than 2003, other factors can influence winter severity. For example, inspection of the ice data in District 9 indicates 2004 often had thinner and easier-to-break ice than 2003. This analysis corroborates one motivation for the construction of the DOMICE model in Analytica®, which was to reflect the effects of variation and uncertainty in weather severity as drivers of DOMICE impacts.

The DOMICE Simulation Model provides USCG Atlantic Area the ability to assess risk associated with ice breaking asset deployments and variations in operational and natural environments. The model's output of the total economic impact of waterway closures informs USCG decision-making processes involved in ice breaking asset allocations in Districts 1 and 9. The model's adaptability based on user-specified inputs allows the risk analysis to focus on specific risk-related scenarios. For example, the risk associated with the assignment of one 140-foot WTGB to a Service Life Extension Program can be analyzed by removing this asset from the icebreaker fleet in a run of the model. Additional manipulation of model inputs allows the user to observe changes in risk as a function of varying winter conditions that may reduce or increase the impacts of assigning the asset to SLEP. By allowing for these and other adjustments of the inputs of the model, the DOMICE Simulation Model strengthens ORAM's ability to represent the risk involved with a number of possible deployment and operating scenarios in order to ensure the most effective utilization of USCG assets in Districts 1 and 9.

5 DETAILED MODEL OVERVIEW AND DESCRIPTION OF VARIABLES

This section provides details on the format and process used to modify key variables of the model. In addition to the descriptions provided here, background information and details regarding data sources and the variable's use in the model are provided for each variable within the *Analytica*® model itself.

The overview of key model variables provided in this section is arranged based on the basic structure of the model, however, individual variables can be found in the *Analytica*® model by selecting the “Find” option from the “Object” menu and entering the “Title” or “Identifier” for the specific variable.

Variables are described here based on the title of the variable, which is the same as the description of the variable shown while navigating the *Analytica*® model. Individual variable titles are shown in bolded font. The “Identifier,” which is used in *Analytica*® to identify individual variables in variable definitions and mathematical expressions, is included in parentheses after the first use of the title of each variable. In many cases, the indices are listed for the variables. Indices define the dimensions of any variable. A variable can hold a different value for each item in an index. For example, the variable “**Length of Waterways**” is indexed by “**Waterway**” and, therefore, holds a different value of length for each waterway in the model.

5.1 Ice Breaking Demand

The “Ice Breaking Demand” module incorporates waterway-specific ice data and vessel traffic data to determine the demand for ice breaking assets on each waterway for each day of the winter navigation season. The module consists of two main sub-modules. One sub-module, or the “Waterway Ice Characteristics and Ice Data” sub-module, is used to process ice data in order to determine whether ice would impede normal vessel traffic on specific waterways each day, in the absence of ice breaking assets. The other sub-module, or the “Waterway Criticality” sub-module, is used to process vessel traffic data in order to prioritize ice breaking activities by ranking waterways in order of their commercial importance.

5.1.1 Waterway Ice Characteristics and Ice Data

For routine use of the model, the user can either select a specific year of District 1 air temperature data and District 9 historical ice data, such as ice data for the 2008-2009 ice season, or the user can allow the model to randomly select a particular year’s ice data in each Monte Carlo iteration. Beyond the basic user interface, the user can make more advanced adjustments to the following variables affecting waterway ice characteristics and ice data.

5.1.1.1 Waterway Geography and Characteristics

The “Waterway Geography and Characteristics” sub-module contains details on basic waterway geography, including the length of the specified waterway. In the sub-module, the variable “**Length of Waterways**” (Length_of_waterways) indicates the length in miles of each waterway that requires ice breaking. The variable is indexed by “Time,” which is measured by day in the ice breaking season, to reflect the fact that many waterways only need ice breaking activities over a portion of their length for some amount of the ice season.

It should be noted that waterway physical lengths – contained in “**Normal Waterway Length**” (Normal_Waterway_Leng) – are multiplied by the variable “**Waterway Length Adjustment**” (Waterway_Length_Adju) to reduce the physical length of the waterway to the length of the waterway actually broken in a single day. For example, only one side of the entry to Eastern Lake Erie is broken on any individual day. In addition, users are permitted to select from “Full” and “Shortened” lengths of selected waterways.

5.1.1.2 Level of Ice Impedance

The sub-module “Waterway Ice Characteristics and Ice Data” contains two key variables that determine the extent to which ice impedes cargo traffic.

The variable “**Waterway Impedance Threshold**” (Waterway_impedance_t) contains the model’s assumptions about the thickness of ice, in feet, needed in order to impede commercial traffic in a waterway. The variable is indexed by both “District” and “Types of Ice,” which include Packed Brash, Loose Brash, and Plate Ice. The baseline assumption populated in the model assumes that commercial vessels in District 9 can tolerate 0.5 feet of ice of any type without impedance, and that vessels in District 1 cannot tolerate any ice without impedance. In other words, the impedance threshold for District 1 is set at 0 feet of ice. To change these assumptions, open the “Edit Table” for the variable and change the values in the table.



The second key variable is the “**Check Current Severity of Conditions**” (Check_current_severi) variable, which defines the weather severity for each day on each waterway. This variable returns either “Severe” or “Moderate” to indicate weekly conditions. Conditions in District 1 are considered “severe” if Cape Cod Canal is iced over, which was determined based on SME input. In District 9, the winter is considered “severe” if the user or model-selected ice season selects the 2003 ice season, which was also determined from SME input indicating that the 2003 winter, or from December 2002 to April 2003, was a severe winter. Analysis of weather data also indicated that 2003 had the lowest annual-average air temperature of all the years ranging from 1998 to 2006 in five of the six District 9 waterways considered. To change these assumptions, open the “Edit Table” for the variable and change the expressions for each District.

5.1.1.3 Historical and Sampled Ice Data

The “Historical and Sampled Ice Data” sub-module uses separate sub-modules to predict ice conditions for District 9 and District 1, due to the differences in ice data availability between the two Districts. The model directly uses historical ice data to determine ice severity in District 9, whereas the model uses statistical ice prediction models in combination with historical air temperature data to determine ice severity in District 1. This section includes variables used in the ice sub-modules for both Districts, as well as variables unique to each District.

5.1.1.3.1 Sub-Modules and Variables Used for Both Districts

In the sub-module “Historical and Sampled Ice Data,” the key variables are directly associated with each year’s ice or weather data and should be updated on an annual basis. Updating ice or weather data requires both adding a new year to the existing set of ice/weather data years in the model, as well as populating the entries for the new year of data in the variables that contain ice or weather data for each year.

To add a new year’s ice or weather data to the model, follow these steps:

- First, in the sub-module “Selection of Ice / Weather Data Year,” open the variable “**Years for Ice Data**” (Years_for_ice_data_) and add a new year to the list of years defined in the variable.
- Second, update the probabilities of selection of each year’s data. This can be done by opening the variable “**Randomly Selected Ice and Weather Data Year**” (Randomly_selected_ic), adding the new year to the variable’s domain, and then updating the probability table in that variable. For example, adding a new year of data will result in the model containing 12 years of ice/weather data instead of 11 years of data. Therefore, replace previous selection probabilities of 1/11 with 1/12, and also assign the new year a selection probability of 1/12. Maintain previous entries of 0 as 0 because those years had data that was too incomplete to use, and should not be used by the model unless new data becomes available for those years.
- Finally, to add the new year’s ice and air temperature data, refer to the sections below on District 9 (Great Lakes) historical ice data and District 1 (East Coast) ice/weather data.

The other main variable contained in this sub-module is the variable “**Waterway exceptions to weather model predictions**” (Waterway_exceptions), which is located in the sub-module “District 1 and 9 Ice Model Combinations and Exceptions.” The “Waterway exceptions to weather model predictions” variable consists of a table with values of 1 or 0 for every waterway that indicate exceptions to the ice and weather model predictions. Values of 1 in the variable’s table indicate that the waterway is an exception to the

model's ice predictions and that that waterway will be treated as never having amounts of ice that would significantly impede commercial traffic. Currently in the model, such exceptions include the New York Harbor and Newark Harbor waterways, as well as all District 1 waterways starting at day 113. Values of 0 in the table indicate that the waterway is not an exception to the model's ice predictions. To modify values in the variable, simply open the "Edit Table" for the variable and change the values in the table.

5.1.1.3.2 Great Lakes Ice Conditions and District 9 Historical Ice Data

The sub-module "District 9 Historical Ice Data" contains historical ice data, as well the interpretation of the SIGRID ice codes into ice thickness estimates.

To add a new year's District 9 ice data to the model, follow these steps:

- First, follow the steps outlined previously in Section 4.1.1.3.1 that describe how to add a new year of data to the list of years defined in the variable "**Years for Ice Data**" (Years_for_ice_data__).
- Second, add new ice data to the variable "**D9 Historical Ice Data (SIGRID Coded) NBL Waterways**" (D9_historical_ice_d3), which contains the historical ice data for District 9 waterways in terms of SIGRID codes for each of the three ice types. The waterways in this variable are coded in order of the outputs for the District 9 waterways that are produced by the automated scripts described separately. There are 19 waterways in District 9 within that "NBL" scheme.

The interpretation of the SIGRID ice codes into ice thickness estimates is also contained within the sub-module "District 9 Historical Ice Data," and specifically, in the variable "**SIGRID code conversion to feet of ice thickness**" (Sigrid_code_conversi). Open the "Edit Table" and make changes to the number of feet of ice that the model translates the SIGRID code into. For example, SIGRID code 84 is currently translated to 0.4921 feet of ice.

5.1.1.3.3 East Coast Ice Conditions and District 1 Ice Regression Modeling

The District 1 (East Coast) ice model uses air temperature data to predict ice thickness. However, regressions of District 9 ice thickness data and air temperature data yielded low R-squared values, indicating that air temperature is not a perfect predictor of ice thickness. The District 1 ice model, therefore, predicts ice thickness using combinations of linear regressions and probabilistic sampling from sets of discretized regression residuals. A regression residual is the difference between an empirically observed data point and the prediction of a regression. The residuals are discretized into sets of histograms or bins for efficient data analysis and model construction.

The linear regressions reflect the extent to which ice thickness depends on air temperature. The regression residuals reflect the extent to which ice thickness depends on other factors besides air temperature. Sampling probabilistically from the regression residuals yields probability distributions representing uncertainty about District 1 waterway ice thicknesses beyond what would be expected given a particular District 1 waterway air temperature. The District 1 weather-ice regression models and sets of residuals are defined for both each week in the ice season (to simulate the time-series profile of ice formation over the course of an ice season) and for each annual ice season (to enable more representative simulation of the distribution of winter severity over a series of years).

The District 1 ice model is based heavily on District 9 ice data, so in some cases, the District 1 ice thickness predictions may resemble District 9 more than District 1. These cases are partly due to the regression analysis indicating that much of the variation in District 9 ice thickness is due to factors besides air temperature. Therefore, it would be appropriate to predict District 1 ice thickness using historical District 1 ice data by sampling probabilistically from the historical observation data as the model does for District 9, if and when this data becomes feasible and affordable.

For the District 1 ice/weather modeling, the sub-module has variables that contain the historical weather or air temperature data and the weather-ice regression/residual model data. To add a new year's District 1 weather data and weather-ice regression/residual data to the model, follow these steps:

- First, follow the steps outlined previously in Section 4.1.1.3.1 that describe how to add a new year of data to the list of years defined in the variable **"Years for Ice Data"** (Years_for_ice_data__).
- Next, in the sub-module "Sampled District 1 Air Temperatures," open the variable **"Historical District 1 Weekly Air Temperature Data"** (Historical_district), which contains the historical air temperature data for District 1 waterways in degrees Fahrenheit.
- Finally, in the sub-modules "District 1 Packed Brash Ice Regression Model and Residual Sampling" and "District 1 Plate Ice Regression Model and Residual Sampling," open and update the variables for the regression model coefficients and discretized sets of regression residuals.
 - The regression model coefficient variables are **"Packed Brash Regression Coefficients"** (Packed_brash_regress) and **"Plate Regression Coefficients"** (Plate_regression_coe).
 - The variables with the residual bin values are **"Packed Brash Resid Hist Bins"** (Packed_brash_resid_h) and **"Plate Resid Hist Bins"** (Plate_resid_hist_bin). The variables with the residual bin probabilities are **"Packed Brash Resid Hist Probs"** (Packed_brash_resid_1) and **"Plate Resid Hist Probs"** (Plate_resid_hist_pro).
 - It should be noted that the values for each of the regression/residual model variables came from a separate Excel file that was used to analyze weather and ice data.

Other important variables are the minimum ice thickness values that the model will allow for brash ice and plate ice. These values are found in the variable **"D1 Minimum Plate Ice Thickness Model Value"** (D1_minimum_plate_ice) in the sub-module "District 1 Plate Ice Regression Model and Residual Sampling" and the variable **"D1 Minimum Packed Brash Ice Thickness Model Value"** (D1_minimum_packed_br) in the sub-module "District 1 Packed Brash Ice Regression Model and Residual Sampling."

If the regression and residual-sampling processes produce predictions of ice thickness below the minimum ice thickness threshold, then the model gives an ice thickness prediction of zero feet of ice. The model uses the thresholds to avoid producing spurious regression/residual ice model predictions that are close to zero feet of ice. Without such a threshold, and assuming that vessels would be blocked by any amount of ice in the waterway, District 1 waterways would frequently be predicted to be closed to vessel traffic due to amounts of ice smaller than amounts ever reported in District 9 historical ice data. The minimum ice thickness variables in District 9 currently have values of 0.492 feet. These values are based partly on the DOMICE models' interpretation of SIGRID ice data, in which the upper end of each SIGRID code's ice

thickness range is used. In addition, the minimum threshold seems to provide qualitatively similar distributions of ice and no-ice presence for District 1 and District 9 waterways in particular years. To modify values in one of the variables, simply open the “Definition” for the variable and change the values in the table.

5.1.2 Waterway Criticality and Vessel Traffic

The criticality of a waterway in the model is defined in terms of the economic impacts that would result from the closure of that waterway due to ice. The sub-module “Waterway Criticality” is mostly a pass-through for results from the separate “Economic Impact” module. Refer to Section 5.2.4.3 on the “Waterway Priority for Asset Assignment” sub-module for further discussion of how the model uses potential economic impacts of a waterway closure in setting icebreaker assignment priorities, or Section 4.3 on the “Waterway Closure Economic Impact” module for further discussion of how economic impacts of waterway closure are calculated.

5.2 Ice Breaking Supply

The “Ice Breaking Supply” module examines the availabilities and capabilities of the designated icebreaker fleet. Several kinds of information are included regarding ice breaking assets, such as: the inventory of icebreaker vessels in the fleet; the functional characteristics of each cutter class; and the unavailability rates of the assets due to other USCG missions and unplanned maintenance. Each of these factors is processed through a sub-module of the “Ice Breaking Supply” module and will be discussed separately here. The module uses these types of information on vessel class characteristics, along with ice data from the demand module, to calculate whether a particular type of ice breaking asset would be capable of breaking the ice present in each waterway for a given model run. Each vessel class’ capabilities and availabilities within a specific model scenario are used to determine the allocation of ice breaking vessels to waterways in each District.

5.2.1 Inventory of Icebreakers

The sub-module “Inventory of Icebreakers,” contains two variables that may require regular updates in order to simulate the effects of taking an asset out of use for an ice season for planned maintenance. These two variables are the user-adjustable input variables “**Baseline Inventory of Icebreakers**” (Baseline_inventory_o) and “**Mid-Season Icebreaker Inventory Adjustments**” (Mid_season_icebreake). It should be noted that users also have easy access to these input variables through the “Basic User Inputs” section of the basic user interface, visible when the DOMICE *Analytica*® model first opens. Both variables offer the user the ability to select a different allocation of icebreakers for two scenarios run simultaneously in the model. The model will run the two allocation schemes simultaneously while all other inputs and variables (e.g., ice conditions) remain static.

These input variables allow the user to set the number of ice breaking vessels of each type that could be used for ice breaking by each District over the course of an ice season, assuming that other missions and unplanned maintenance do not make a particular asset unavailable for ice breaking in a particular day. The two user-adjustable input variables are summed by the calculation variable “**Adjusted Inventory of Icebreakers**” (Adjusted_inventory_) to determine the inventories in any particular day.

To set a “baseline” number of assets of each type that generally applies to the entire ice season, open the variable “**Baseline Inventory of Icebreakers**” (Baseline_inventory_o) and revise the “Edit Table.”

To make mid-season, or week-by-week, modifications to the “baseline” number of assets of each type, open the variable “**Mid-Season Icebreaker Inventory Adjustments**” (Mid_season_icebreak) and revise the “Edit Table.” The values in “Mid-Season Icebreaker Inventory Adjustments” indicate a mid-season change in comparison to the “baseline” values. For example, a value of 1 in “Mid-Season Icebreaker Inventory Adjustments” indicates that an additional asset of a particular cutter class is added to the “baseline” inventory for that particular week. A value of 0 in “Mid-Season Icebreaker Inventory Adjustments” indicates that there is no change from the “baseline” inventory for that type of asset in that week.

5.2.2 Characteristics of Icebreakers

In the sub-module “Characteristics of Icebreakers,” there are several key variables related to icebreaker capabilities. These include the variables for Ice Breaking Capacities; Asset Ice Breaking Speeds; Number of Passes Needed per Day; and Transit Time.

The variable “**Ice Breaking Capacities**” (Ice_breaking_capacit) contains the ice breaking capabilities of each asset type in terms of how many feet of ice, for each the three identified types of ice, an asset of a particular cutter class can break. For example, the 140’ WYTG assets are currently assumed to be able to break 2 feet of solid level ice and 6 feet of either loose brash or packed brash ice. To change these capabilities, open the variable, then open and revise the “Edit Table.”

The variable “**Asset Ice Breaking Speeds**” (Asset_ice_breaking_s) contains the speed at which an icebreaker can operate for each combination of the following factors: the type of clearing activity conducted, which can either be direct clearing of the waterway or indirect/preventative clearing; weather severity, which can either be “severe” or “moderate” conditions; District; and Time, which represents the day in the ice season. To change these speeds, open the variable, then open and revise the “Edit Table.”

The variable “**Number of Passes Needed per Day**” (Number_of_passes_nee) contains the number of passes needed per day to maintain a waterway open to traffic. One pass is defined as breaking ice along the full length of the waterway. The variable is indexed by the following factors: the type of clearing activity conducted, which can either be direct clearing of the waterway or indirect/preventative clearing; weather severity, which can either be “severe” or “moderate” conditions; District; and Time, which represents the day in the ice season. To change the numbers of passes needed, open the variable, then open and revise the “Edit Table.”

5.2.2.1 Transit Time

The sub-module “Transit Time” calculates the transit time required for vessels to move from waterway to waterway in each day of the simulation.

The variable “**Waterway to Waterway Distance**” (Waterway_to_Waterway) represents the distance in miles from each waterway to the other waterways in that district. While the actual distance from a waterway to itself is 0 miles, the model has these distances coded as 5000 to ensure that when moving an asset, the accurate transit time is calculated. Specifying these distances as 5000 – an unrealistically high number – it ensure the model determines the closest other waterway; a separate check is completed in the model to determine if an icebreaker was deployed in the same waterway on the previous day. The model

makes a separate check to see if no transit time is needed under the variable “**Check if there were any icebreakers within a class within a district that were not assigned last day**” (Check_if_there_were_). To change transit distances, open the variable, then open and revise the “Edit Table.”

The variable “**Asset Transit Speed**” (Asset_Transit_Speed) defines the speed at which assets can transit from one waterway to the other. This is defined for each class of asset. To change the asset transit speed, open the variable, then open and revise the “Edit Table.”

5.2.3 Probability of Ice Breaking Asset Being Unavailable

In the sub-module “Other Missions and Maintenance of Icebreakers,” key variables include the variables for expected hours for other missions and for historical availabilities that reflect the rates of unavailability due to unplanned maintenance. Both variables are used to estimate the probability that an asset will be unavailable for ice breaking in a particular day because of non-ice breaking missions or because of unplanned maintenance needs.

The model uses information on historical availabilities to estimate the probability that a particular asset will be unavailable in a particular day due to unplanned maintenance. The model assumes that a need for unplanned maintenance can arise at any point in the ice season, and that if a need for unplanned maintenance of an asset arises in a particular day, it will also be repaired that same day. Most of the values in the “Historical Availabilities” variable are the historical availability rates for each asset type in the years 2006 through 2009, as provided by the USCG DOMICE Mission Analysis Report (MAR), which are expressed as the percent of time free from major casualties. The only exception to the use of these historical availability rates is the 240’ Mackinaw, which has had 100% availability each of the three years it has been in service, despite only having a 95% target availability rate. The default data in the sub-module assumes that half of the time the 240’ should be expected to have a 100% availability rate, and that it should be expected to have a 95% availability rate the other half of the time.

There are two types of possible changes that can be made to the variable “**Historical Availabilities**” (Historical_availability), which include either modifying the availability rates in the availability data years 2006 through 2009, or adding and populating new availability data years. To modify availability rates for previously-defined availability data years, simply open the “Edit Table” for the “Historical Availabilities” variable and change the values in the table. To add new availability data years:

- Open the “availability data years” variable and add a new availability data year.
- Open the “Edit Table” for the “Historical Availabilities” variable and define a value in the table for the new availability data year.
- Open the “Edit Table” for the “Probability of sampling from an Availability Data Year” variable and revise the values in the table to give equal probability of selection to each data year.

The model uses information on expected hours for other missions, contained in the variable “**Expected Hours for Other Missions**” (Expected_hours_for_o), to estimate the probability that a particular asset will be unavailable for ice breaking in a particular day due to other USCG missions. The model currently does not assign any hours to other missions. To modify values in the variable, simply open the “Edit Table” for the variable and change the values in the table.

5.2.4 Assignment of Icebreakers to Waterways

There are a number of factors involved in the model's ice breaker asset assignment process, including factors in the following assignment sub-modules: Time and Weather Dependent Rules on Types of Ice Breaking; SAR Standby Duty Requirements; Waterway Priority for Asset Assignment; and Other Factors Considered During Ice Breaker Assignment. The key variables contained in each sub-module are described below.

5.2.4.1 *Tables for Time and Weather Dependent Rules on Types of Ice Breaking*

The sub-module "Tables for Time and Weather Dependent Rules on Types of Ice Breaking" contains variables defining different types of ice breaking policies considered in assigning assets.

The variable "**Type of ice breaking that should NOT be performed, where known ahead of time**" (Type_of_ice_breaki17) is a table that contains values of 1 to indicate waterways on which one of these types of clearing activities is specified as not occurring, and values of 0 to indicate where the type of clearing activity is allowed. If an exclusion is not created, the model will assign icebreakers to perform direct/clearing runs, if available, after making indirect/maintenance assignments. To modify values in the variable, simply open the "Edit Table" for the variable and change the values in the table.

The variable "**Severe-weather assignments of D1 assets**" (Severe_weather_assig) is a table that contains the non-zero number of assets of each cutter class that should be assigned during severe weather to specific rivers for specific types of ice breaking activities. This table outputs the value of 0 to indicate cases in which no specific numbers of assets are known in advance to be needed during severe weather. To modify values in the variable, simply open the "Edit Table" for the variable and change the values in the table.

The variable "**Locations where particular classes of assets will never be deployed**" (Locations_where_part) is a table that contains a value of 1 to indicate waterways where a particular class of asset will never be deployed, and a 0 to indicate the asset class could be deployed to that waterway. This variable is used to define waterways where an asset class is physically incapable of operating, or locations where a particular class of asset (e.g., 240' Heavy icebreaker) will not be deployed. To modify values in the variable, simply open the "Edit Table" for the variable and change the values in the table.

The variable "**Waterway closures in either District**" (Waterway_closures_in) is a table containing values of 1 and 0, in which values of 1 indicate that waterway closures are specified by these rules, and values of 0 indicate that ice breaking activities could still occur according to other rules. If a waterway is closed, there will be no assignments of icebreakers from that District to keep that waterway open. It should be noted that this variable is used to indicate waterways and days in which AIS vessel traffic data is overridden in order to indicate that there is no vessel traffic and that no traffic impedance is occurring. For instance, for cases in which a particular waterway is allowed to be closed, there is no real-world economic impact of those closures because vessels would not travel the waterway in that time period. To modify values in the variable, simply open the "Edit Table" for the variable and change the values in the table.

5.2.4.2 *SAR Standby Duty Requirements*

The sub-module "SAR Standby Duty Requirements" contains variables that define the current SARGARD rules for District 9 and influence vessel assignment.

The variable “**SAR Standby Areas**” (Sar_standby_areas) is a list of areas within District 9 that typically require an asset to perform SAR standby duty, with some exceptions. Each of the Great Lakes is designated as a separate SAR Standby Area. Though the list of SAR Standby areas is unlikely to require an update, the list could be modified if necessary by opening the variable and editing the list of SAR standby areas.

The variable “**Waterways in each SAR standby area**” (Waterways_in_each_sa) is a table containing values of 1 or 0 for each combination of Waterway and SAR Standby Area. The variable is assigned a value of 1 if a waterway is located in a particular SAR Standby Area. Otherwise, the variable is assigned values of 0. For example, the waterways in the Lake Superior SAR standby area are Thunder Bay, Western Lake Superior, and the Sault Ste. Marie Waterway System, and each of these waterways would be assigned a value of 1. To modify values in the variable, simply open the “Edit Table” for the variable and change the values in the table.

The variable “**Times for SAR Standby duty**” (Times_for_sar_standb) is a table containing values of 1 or 0 for each combination of the day of the ice season and the SAR Standby Area. The variable has a value of 1 if SAR Standby duty will affect waterway priority for a particular day in that SAR Standby Area. Otherwise, the variable has values of 0. For example, the Lake Michigan SAR Standby Area has values of 1 from the beginning of the ice season until day 15, but the Lake Ontario SAR Standby Area never has values of 1 because SAR standby duty is not performed there. To modify values in the variable, simply open the “Edit Table” for the variable and change the values in the table.

5.2.4.3 Waterway Priority for Asset Assignment

The sub-module “Waterway Priority for Asset Assignment” contains the variable “**Order of waterways for asset assignment as function of AIS data**” (Order_of_waterway100) to initially prioritize waterways primarily based on an analysis of AIS or equivalent daily vessel traffic data. AIS or equivalent data is contained in the variable “**Vessel Number**” (vessel_number). The sub-module uses the total economic value of cargo in each waterway for the year, contained in the variable “**Total Potential Waterway Impact**” (Total_potential_wate), to break ties between waterways in the assignment process, if necessary.

Waterway prioritization is also accomplished by the variable “**Waterway Importance by Asset Class**” (Waterway_Importance1), which allows the user to select the importance of each waterway for each asset classification. This is used to apply additional weights each waterway with a multiple to increase or decrease priority. Each waterway is assigned linguistic value ranging from “highest priority” to “lowest priority.” All waterways were set with a default of “Average” and then adjusted based on SME input. This is used primarily for asset classifications with a low number of icebreakers (e.g., Canadian icebreakers) to further refine the priorities for that particular classification of asset. The variable is created as a Choice table, where the importance of each asset classification/waterway pairing can be selected from a drop down menu. To change the importance of any waterway/asset classification pairing, select “Browse Mode” from Analytica® and open the table.

The different levels of importance are included in the variable “**Waterway Importance Levels**” (Waterway_Importance_). These linguistic expressions are converted to a numerical weighting factor with values from 10,000 to 0.01, in orders of magnitude of 10. This variable allows the user to emphasize or deemphasize certain waterways for particular asset classifications. The conversion levels for each importance level are contained in the variable “**Priority Conversion**” (Priority_Conversion).

The “**Order of waterways for asset assignment as function of AIS data**” variable is set equal to $1G * \text{Vessel_number} + (\text{Total_potential_water} / 1G)$. The “1G” terms, with “1G” being shorthand for “equal to 1 billion,” are used as simple weighting factors so that, when comparing two waterways, the difference between the “Total Potential Waterway Impact” of the two waterways results in waterway ordering differences only if there is no difference between the “Vessel Number” of the two waterways. This value is then multiplied by the “**Waterway Importance by Asset Class**” values to determine a final prioritization for waterways. To change the definition of the variable, open the “Definition” field for the variable and change the definition.

5.2.4.4 *Other Factors Considered During Ice Breaker Assignment*

In the sub-module “Other Factors Considered During Ice Breaker Assignment,” there are several variables that define basic operational factors considered in ice breaking assignment.

The variable “**Daylight hours**” (Daylight_hours) is a table indexed by Time, District, and Asset Classification. The variable provides the model-assumed number of ice breaking hours per day in each case. The domestic ice breaking assets have daylight hours ranging from 9 hours per day in Week 1 to 12 hours per day in Week 20. The Canadian assets have 24 “daylight” hours per day, indicating they break ice at night if necessary. To modify values in the variable, simply open the “Edit Table” for the variable and change the values in the table.

5.2.4.5 *Sequential Ice Breaker Assignments: Assignment of Icebreakers to any Advance Assignments*

In the sub-module for “Sequential Ice Breaker Assignments,” there are a series of additional sub-modules for assignment steps. The sub-module “Assignment of Icebreakers to any Advance Assignments” contains the variable “**Advance assignments of icebreakers**” (Advance_assignments), which describes cases in which pre-determined assignment rules will be enforced.

The variable “Advance assignments of icebreakers” is a table containing the number of assets of each cutter class that should be assigned in advance to specific waterways for specific days, regardless of the ice/weather model predictions of ice or weather severity. For example, from January 10 (Week 5) to February 15 (the end of Week 9), one 140' icebreaker is dispatched to clear ice in the lower Hudson River, which is named the Manhattan River System in the waterway system scheme of the model. The variable has values of 0 in cases in which no specific numbers of assets are known in advance to be needed. To modify values in the variable, simply open the “Edit Table” for the variable and change the values in the table.

The sequential assignment of assets is performed through a series of separate sub-modules, with each sub-module designed for a specific cutter class and a specific type of ice breaking activity. For instance, the assignment of 65s to track maintenance has a separate sub-module than the assignment of 140s to track maintenance. Similarly, the assignment of 65s to active/direct clearing has a separate sub-module than the assignment of 65s to track maintenance. Vessel assignments are determined one asset or one pair of assets at a time in each District, in order to avoid exceeding available inventories of assets in the District. Once an assignment of one asset or one pair of assets is made, the sub-module proceeds to consider making another assignment of the same type of asset. If all of the above conditions are not met by that asset type, the sub-module does not make any more assignments of assets of that cutter class and, instead, considers the vessels of the next asset type. Once the sub-module has made assignments for all the available assets in the current day, it then proceeds to determine assignments for the following day.

The icebreaker assignment sub-modules consider the assignment of assets to track maintenance separately from assignments for direct clearing. The sub-modules also consider the timing of assignments when considering maintenance assignments. For each day, the sub-modules consider assignments in the following order:

- 1) Assignment of assets to maintain any tracks where track maintenance was being performed in the previous day;
- 2) Assignment of assets to active clearing needed this day; and
- 3) Assignment of any remaining assets to maintain tracks that are being cleared this day.

At each of the numbered steps above, the assignment sub-modules also consider each class of ice breaking asset in a specific order that reflects the increasing capability of assets to break ice. This order is followed to focus the most capable assets to the waterways in which their capabilities would be put to greatest use. The 240 is assigned first by the sub-modules, and is usually assigned either to the Sault Ste. Marie System or the Detroit River System. The assignment of 65s is considered second, followed by the assignment of Canadian Assets, which are 1050s or 1100s. The 140s are considered for the next assignments. Lastly, the 225s and 175s are assigned, with 175s being the last cutter class considered. The 225s and 175s are the final vessels considered for assignment due to their role as backups to other assets in the fleet and to ensure that these assets are only used if all vessels of other cutter classes are not able to meet ice breaking needs.

The successive assignment of assets to waterways is implemented in each sub-module using a series of vertically repeating assignment steps. This structure allows the sub-module to function in a way similar to that of calculations organized in a single column of a spreadsheet. For example, the second assignment step following the assignment of the 240 is for the first sequential assignment of available 65s to maintain any tracks where track maintenance was being performed the previous day. The calculations specific to that assignment step are organized horizontally. The calculations specific to the second assignment are found in the second row, and so on. Enough sets of calculations are provided to allow for a number of assignments of each asset type to a particular type of ice breaking activity that is more than adequate for current (2012) inventories in District 1 and District 9. For example, the model has provision for up to 10 successive assignments of 65s to continuing track maintenance, which exceeds the inventories of 65s in either District. Each assignment step also includes bug-fix calculations designed to correct patterns of erroneous assignments (the **“Make Workaround Waterway assignments go to zero”** and **“Make other excess assignment go to zero”** variable nodes) that were identified during model development.

The final output of the “Assignment of Icebreakers to Waterways” sub-module is the number of assets of each cutter class assigned to each waterway for each day in each District.

5.3 Waterway Closure Economic Impact

The outputs from the “Ice Breaking Demand” and “Ice Breaking Supply” modules are used to determine the length of time a waterway would remain closed to vessel traffic as a result of the demand for ice breaking activities being unmet by the supply of available ice breaking assets. The third module, or the Waterway Closure “Economic Impact” module, calculates the economic impact of the waterway closures that occur in an ice breaking season due to this unmet demand. Economic impact is calculated based on two main types

of impacts, namely, cargo shipping impacts and flooding impacts. The module's output is the total economic impact of waterway closures for the entire season. The sub-modules and corresponding key variables used to calculate the total economic impact are described here.

5.3.1 Cargo Volumes

5.3.1.1 District 9 Cargo Flow

In the module, the average quantity of goods shipped on each vessel in District 9 is determined based on known commodity flows and known vessel traffic data. The variable **"Annual USACE Volume by Waterway"** (Usace_vol_w9) is a table containing the annual cargo flows for selected waterways. The variable only contains data for those waterways tracked by the US Army Corps of Engineers. In order to add additional data, the index **"USACE Year"** (Usace_year) must also be updated with the additional new year.

The variable **"Ice Season Waterway Traffic"** (Ais_w_is9) contains annual summary counts of all vessel traffic for each waterway for each year with available data. In order to add additional data, the index **"AIS Year"** (Ais_year) must be updated with the additional new year.

To allocate annual cargo flows over the course of the season, the variables **"LCA Cargo Ice Season"** (Lca_vol_ice) and **"LCA Cargo Annual"** (Lca_cargo_annual) can be adjusted or updated. Each variable is a table containing the total flow of cargo, in tons, reported by the Lake Carriers' Association for the entire year and the respective ice season. Both variables use the index **"USACE Year"** (Usace_year).

The value of each type of cargo is contained in the variable **"D9 Cargo Value by Ton of Cargo by Cargo Type"** (D9_cargo_value). The value of cargo by cargo type is derived from the US Economic Census, which is conducted every five years.

5.3.1.2 District 1 Cargo Flow

As for District 9, the average quantity of goods shipped on each vessel in District 1 is determined based on known commodity flows and known vessel traffic data. The variable **"Annual USACE Volume by Waterway"** (Usace_vol_w2) is a table containing the annual cargo flows for selected waterways. The variable only contains data for those waterways tracked by the US Army Corps of Engineers. In order to add additional data, the index **"USACE Year"** (Usace_year) must also be updated with the additional new year.

The variable **"Ice Season Waterway Traffic"** (Ais_w_d2) contains annual summary counts of all vessel traffic for each waterway for each year available. In order to add additional data, the index **"AIS Year"** (Ais_year) must be updated with the additional new year.

The value of each type of cargo is contained in the variable **"D1 Cargo Value by Ton of Cargo by Cargo Type"** (D1_cargo_value). The value of cargo by cargo type is derived from the US Economic Census, which is conducted every five years.

5.3.2 Vessel Volume, Value, and Number

The sub-modules containing information on vessel volume, value, and number are used as key inputs in determining the economic impact of closed waterways.

5.3.2.1 Vessel Number

The “Vessel Number” sub-module contains essential data on the daily vessel traffic found on each waterway. The variables “**D9 Vessels per Historical Year**” (D9_vessels_per_histo) and “**D1 Vessels Per Historical Year**” (D1_vessels_per_histo) contain this data. Both variables are indexed by Waterway and Time, and by the index “**Ais Year**” (Ais_year), which would need to be updated to add additional years of data.

Variables for District 9, “**D9 Year Relative Probabilities**” (D9_year_relative_pro), and District 1, “**D1 Year Relative Probabilities**” (D1_year_relative_pro), contain the relative probability for selecting each year’s vessel traffic patterns. The model currently allocates an equal probability of selecting all available data.

The variable “**Waterway closures in either District**” (Waterway_closures_in) adjusts the number of vessels in each waterway based on ice breaking and ice use rules. If a waterway is closed for vessel traffic for a day for recreational ice use, for example, then the table is populated with a value of 1. This table modifies the vessel numbers determined from historical data to ensure that the absence of vessel traffic in a “closed” waterway is not considered as an economic impact.

5.3.2.2 Waterway Cargo Volume

The variable “**Waterway Cargo Volume**” (Cargovolume) contains the total cargo flow through each waterway for each day, based on the results from the vessel traffic sub-module and the District 1 and District 9 Cargo Flow sub-modules. The data is automatically updated.

5.3.2.3 Waterway Cargo Value

The variable “**Waterway Cargo Value**” (Cargoval) contains the total value of all cargo flows through each waterway for each day, based on the results from the vessel traffic sub-module and the District 1 and District 9 Cargo Flow sub-modules. The data is automatically updated.

5.3.2.4 Impeded Vessels, Cargo Volume and Cargo Value

The variables for “Vessel Number,” “Waterway Cargo Volume,” and “Waterway Cargo Value” are all multiplied by the variable “**Waterway Closure**” (Closure) to determine the total impeded amount of vessels, cargo volume, and cargo value for each waterway for each day of the ice season.

5.3.2.5 Cumulative Volume Impeded

The sub-module “Cumulative Volume Impeded” compares the total impeded volume of cargo in District 9 with the total capacity of the “Laker” fleet. The variables “**D9 Extended Navigation Capacity**” (D9_en2), “**D9 Closed Season Capacity**” (D9_cs2), and “**D9 Spring Breakout Capacity**” (D9_sb2) record the capacity for the “Laker” fleet for the past four years. The range of capacity can be updated based on the LCA’s annual statistical report. The low amount of annual variation does not, however, make regular updating necessary.

5.3.3 Cargo and Home Heating Oil Impact

The sub-module for “Cargo and Home Heating Oil Impact” evaluates the total economic impact due to the costs of shipping goods by alternate modes (“Alternative Shipping Impact”), costs to vessel owners and operators (“Operating Costs”), and costs to downstream consumers of commercial goods (“Downstream Costs”). The three sub-modules are combined in the variable “**Cargo Economic Impact**” (I_total) to determine the total economic impact for each waterway on a day by day basis.

5.3.3.1 Alternative Shipping Impact

The costs of shipping goods through alternative modes are considered in this sub-module. The variable “**Alternate Costs**” (Alternate_Costs) includes the costs per unit ton incurred to ship goods by means of overland routes. These costs were determined from a study conducted by the US Army Corps of Engineers. The variable contains a table with a range of costs for each type of commodity transported and the table can be updated to reflect changes in overland cost estimates. These costs are calculated based on the impeded cargo volume of Home Heating Oil in District 1 and all commodity types in District 9.

5.3.3.2 Operating Costs

The operating costs sub-module contains details on the daily costs to vessel owners and operators incurred due to delays in shipments. The variable “**Vessel Classes**” (Vessel_classes) is the basis of this sub-module and includes a list of all vessel classes considered. The variable “**Vessel Operating Costs**” (Vessel_operating_cos) contains data on the daily operating cost for each of the vessel classes. The variable “**Vessel Class Probabilities**” (Vessel_class_probabi) contains the relative probability of selecting an individual operating cost. All three variables must be updated to add new classes of vessels.

5.3.3.3 Downstream Impact

The sub-module for downstream impacts includes separate key variables for District 1, “**D1 Downstream Unit Impact**” (D1_d_unit), and District 9, “**D9 Downstream Unit Impact**” (D9_d_unit). Both variables are tables containing the downstream impact to consumers for delayed cargo. Both tables are based on an assumed cost of \$10,000 for one hour of delay in the cargo shipment. Both are indexed by Cargo type and contain a range of values based on current economic research and modeling.

5.3.3.4 Impact Decision

The variable “**D9 Impact Decision**” (D9_impact_decision) contains the formula for determining whether the immediate economic impacts are calculated based on alternative shipping impacts or owner and operator impacts. This variable compares the cumulative value of cargo impeded for each day of the ice season to the total capacity of the “Laker” fleet for that sub-season. If the cumulative volume impeded is less than the total capacity, then costs to owners and operators are assigned for that day. If the cumulative volume impeded exceeds the “Laker” fleet’s capacity, costs of shipping goods by land transport are assigned for that day.

No “decision” is required for District 1; all home heating oil is assumed to be shipped overland while all other cargo is assumed to be delayed. Therefore, this variable combines the costs associated with both alternative shipping modes and owner/operator costs into a single cost for all cargo types.

In order to consider a different combination of impacts for each District, the “Definition” can be edited in each variable to include a different set of costs.

5.3.4 Flooding Impact

The “Flooding Impact” sub-module contains details on the potential impact of flooding for applicable waterways.

5.3.4.1 Flooding Probabilities

The variable “**Flood Occurrence Probabilities Given Closure**” (Flood_occurance_prob) represents a key variable containing the probability of flooding occurring in each waterway for each week of the season. The probability of occurrence is expressed as a Bernoulli function with a unique probability value for each waterway and the first day of each week. The probability values are based on NOAA data on historical floods, and could be updated based on increased historical knowledge.

Evaluating flooding simply at some point in the week therefore allows the model to better account for the uncertainty of exactly when in the week flooding will occur, the slower build up in flooding conditions, and USCG’s ability to mitigate the risk. Unlike ice formation, which can occur in only a few hours, conditions for flooding build up over the course of several days. It is therefore more difficult to predict exactly when flooding will occur, and also gives the USCG the opportunity to proactively prevent flooding. By only checking for flooding once on a weekly basis, the model can evaluate if the deployment activities of icebreakers in the week are sufficient to prevent flooding from actually occurring.

The variable “**Flood Occurrence Probabilities**” (Flood_occurance_pro1), determines if flooding occurs in a waterway for a particular week. If the variable “Flood Occurrence Probabilities Given Closure” returns a value of 1, indicating flood conditions exist for that week, the variable “Flood Occurrence Probabilities” checks how many days icebreakers operated in that waterway for the week. If icebreakers operate for a sufficient number of days – initially set at three in District 1 and one in District 9 – then the variable returns a value of 0, indicating no flooding has occurred. If icebreakers do not operate a sufficient number of days, the variable returns a value of 1, and the model calculates flooding impact for that waterway. To change the required number of days of icebreaking, simply open the “Edit Table” for the variable and change the values in the table.

5.3.4.2 Flooding Impact by Waterway

The sub-module “Flooding Impact by Waterway” is used to determine the conditional impact of flooding for each of the waterways, or in other words, the impact of flooding if it were to occur. A set of variables exists for each waterway with an index and a “**Values**” and “**Probs**” variable for each. The “Values” variable contains a table with potential levels of economic impact, based on historical probabilities. The “Probs” variable contains a table with the probability of each level of economic impact being selected. The resulting probability distribution function for each waterway is created as a chance variable, “**PDF**,” based on the values and probabilities for each waterway. Updating the data for a given waterway would require updating the index, and the Values and Probs variables for the waterway, though regular maintenance of this sub-module should not be required.

5.4 DOMICE Outcomes

The “DOMICE Outcomes” module contains several types of model outputs. All of the outputs relate in some way to the results of simulation runs and the predicted cases of waterway closures due to ice breaking demands not being met by icebreaker allocations. In general, each output can be produced by selecting the variable for a particular output and using *Analytica*® to run the model and produce the specific variable’s results. For example, an output can be produced by selecting or left-clicking on a particular variable and selecting “Show Result” from the Result menu. Users also have easy access to these and other model outputs in the “Basic User Outputs” section of the basic user interface, visible when the DOMICE *Analytica*® model first opens.

The variable “**Days that ice breaking demands cannot be met after icebreaker allocations and waterways are closed to traffic**” (Weeks_that_ice_break) provides basic information on waterway closure with outputs of 1 or 0 for each waterway for each day of the ice season. A value of 1 indicates that the waterway is closed for that day and a value of 0 indicates that the waterway is either maintained for that day or cleared at least once in that week as a direct assistance.

The sub-module “Calculations of hours of unused ice breaker availability,” contains the variables “**Hours of effective icebreaker availability of each asset type left over after asset allocations**” (Hours_of_effective_i) and “**Hours of icebreaker availability that would be needed to meet unmet demand**” (Hours_of_icebreaker), which both contain the calculations related to unused icebreaker availability.

The first variable, “Hours of effective icebreaker availability of each asset type left over after asset allocations,” provides the number of hours of ice breaking that assigned assets could have performed beyond the requisite number of passes per day in their assigned waterway or waterway system. The variable indicates, therefore, the unused ice breaking hours for each waterway, by day and asset type. The variable accounts for only assigned assets, and does not account for assets that were not assigned at all, even though presumably all assets would have been assigned somewhere if they were needed and were capable of breaking the types of ice on remaining waterways. The calculation of effective hours includes the subtraction of transit time, if an asset moved from one waterway to another.

The second variable, “Hours of icebreaker availability that would be needed to meet unmet demand,” calculates how many hours of ice breaking would be needed in a waterway to keep it open for a day. This variable assumes that ice breakers would use the number of passes, and ice breaking speed, for either direct clearing passes or for maintenance passes. It should be noted that the variable does not indicate what type of asset would be needed to break ice of whatever thickness is present in the waterway.

The “DOMICE Outcomes” module also includes the variables “**Total economic impact of waterway closures after icebreaker allocations**” (Total_economic_impac), “**Total Economic Impact after closure summed by waterway and Day**” (Total_economic_impac6), and “**Total Economic Impact for each district after closure summed by Waterway and Day**” (Total_economic_impac4). Each of these variables has the same economic-impact output information, but each variable combines the information in different ways. The “Total economic impact of waterway closures after icebreaker allocations” variable generates the estimated economic impact for each waterway by day. The other two variables sum the economic impacts by waterway and day for District 9 and District 1 either together or separately.



Other intermediate outputs that are important to the model's functions include the “**Intermediate-step Total economic impact of waterway closures after icebreaker allocations**” (Intermediate_step_to) variable, which provides the economic impacts of predicted waterway closures directly from the model's economic impact module, or “DOMICE Economic Impact” module. The output from that variable is an input to the variable “**Total economic impact of waterway closures after icebreaker allocations**” (Total_economic_impac).

6 UPDATE FREQUENCY OF MODEL VARIABLES AND KNOWN ISSUES

6.1 Update Frequency

This section provides a summary of key model variables for convenient referencing by advanced model users in both regular and advanced uses of the model, including model data updates. This summary is organized into the following three categories:

- 1) Variables whose values may be changed as part of regular model use or sensitivity analysis;
- 2) Variables whose values would ideally be updated annually (e.g. weather and ice data), or when new information becomes available (e.g. every five years for cargo value data); and
- 3) Variables whose values should be checked or updated periodically (e.g. every three years) to ensure consistency with current ice breaking practices, or modified as needed for sensitivity analysis.

The variables in each category are listed below, along with the location in this User Guide where the variable is described in further detail. Within each category, the variables are presented in order of their appearance in this User Guide.

1) Variables whose values may be changed as part of regular model use or sensitivity analysis:

- “Baseline Inventory of Icebreakers” (see Section 3.1 of this User Guide)
- “Mid-Season Icebreaker Inventory Adjustments” (see Section 3.1 of this User Guide)

2) Variables whose values would ideally be updated annually (e.g. weather and ice data), or when new information becomes available (e.g. every five years for cargo value data):

- “Years for Ice Data” (see Section 5.1.1.3.1 of this User Guide)
- “Randomly Selected Ice and Weather Data Year” (see Section 5.1.1.3.1 of this User Guide)
- “D9 Historical Ice Data (SIGRID Coded) NBL Waterways” (see Section 5.1.1.3.2 of this User Guide)
- “Historical District 1 Weekly Air Temperature Data” (see Section 5.1.1.3.3 of this User Guide)
- “Packed Brash Regression Coefficients” (see Section 5.1.1.3.3 of this User Guide)
- “Plate Regression Coefficients” (see Section 5.1.1.3.3 of this User Guide)
- “Packed Brash Resid Hist Bins” (see Section 5.1.1.3.3 of this User Guide)
- “Plate Resid Hist Bins” (see Section 5.1.3.3 of this User Guide)
- “Packed Brash Resid Hist Probs” (see Section 5.1.1.3.3 of this User Guide)

- “Plate Resid Hist Probs” (see Section 5.1.1.3.3 of this User Guide)
- “Historical Availabilities” (see Section 5.2.3 of this User Guide)
- “Annual USACE Volume by Waterway” (see Section 5.3.1.1 of this User Guide)
- “USACE Year” (see both Sections 5.3.1.1 and 5.3.1.2 of this User Guide)
- “Ice Season Waterway Traffic” (see both Sections 5.3.1.1 and 5.3.1.2 of this User Guide)
- “LCA Cargo Ice Season” (see Section 5.3.1.1 of this User Guide)
- “D9 Cargo Value by Ton of Cargo by Cargo Type” (see Section 5.3.1.1 of this User Guide)
- “D1 Cargo Value by Ton of Cargo by Cargo Type” (see Section 5.3.1.2 of this User Guide)
- “D9 Vessels per Historical Year” (see Section 5.3.2.1 of this User Guide)
- “D1 Vessels Per Historical Year” (see Section 5.3.2.1 of this User Guide)
- “D9 Year Relative Probabilities” (see Section 5.3.2.1 of this User Guide)
- “D1 Year Relative Probabilities” (see Section 5.3.2.1 of this User Guide)
- “D9 Extended Navigation Capacity” (see Section 5.3.2.5 of this User Guide)
- “D9 Closed Season Capacity” (see Section 5.3.2.5 of this User Guide)
- “D9 Spring Breakout Capacity” (see Section 5.3.2.5 of this User Guide)
- “Alternate Costs” (see Section 5.3.3.1 of this User Guide)
- “Vessel Classes” (see Section 5.3.3.2 of this User Guide)
- “Vessel Operating Costs” (see Section 5.3.3.2 of this User Guide)
- “Vessel Class Probabilities” (see Section 5.3.3.2 of this User Guide)
- “D1 Downstream Unit Impact” (see Section 5.3.3.3 of this User Guide)
- “D9 Downstream Unit Impact” (see Section 5.3.3.3 of this User Guide)
- “Flood Occurrence Probabilities Given Closure” (see Section 5.3.4.1 of this User Guide)
- Flooding Impact “Values” and “Probs” (see Section 5.3.4.2 of this User Guide)

3) Variables whose values should be checked or updated periodically (e.g. every three years) to ensure consistency with current ice breaking practices, or modified as needed for sensitivity analysis :

- “Length of Waterways” (see Section 5.1.1.1 of this User Guide)
- “Waterway Impedance Threshold” (see Section 5.1.1.2 of this User Guide)
- “Check Current Severity of Conditions” (see Section 5.1.1.2 of this User Guide)
- “Waterway exceptions to weather model predictions” (see Section 5.1.1.3.1 of this User Guide)
- “SIGRID code conversion to feet of ice thickness” (see Section 5.1.1.3.2 of this User Guide)
- “D1 Minimum Plate Ice Thickness Model Value” (see Section 5.1.1.3.3 of this User Guide)
- “D1 Minimum Packed Brush Ice Thickness Model Value” (see Section 5.1.1.3.3 of this User Guide)
- “Ice Breaking Capacities” (see Section 5.2.2 of this User Guide)
- “Asset Ice Breaking Speeds” (see Section 5.2.2 of this User Guide)
- “Number of Passes Needed per Week” (see Section 5.2.2 of this User Guide)
- “Transit Time” (see Section 5.2.2 of this User Guide)
- “Expected Hours for Other Missions” (see Section 5.2.3 of this User Guide)

- “Type of ice breaking that should NOT be performed, where known ahead of time” (see Section 5.2.4.1 of this User Guide)
- “Severe-weather assignments of D1 assets” (see Section 5.2.4.1 of this User Guide)
- “Waterway closures in either District” (see Section 5.2.4.1 of this User Guide)
- “SAR Standby Areas” (see Section 5.2.4.2 of this User Guide)
- “Waterways in each SAR standby area” (see Section 5.2.4.2 of this User Guide)
- “Times for SAR Standby duty” (see Section 5.2.4.2 of this User Guide)
- “Order of waterways for asset assignment as function of AIS data” (see Section 5.2.4.3 of this User Guide)
- “Working days per week” (see Section 5.2.4.4 of this User Guide)
- “Daylight hours” (see Section 5.2.4.4 of this User Guide)
- “Advance assignments of D1 65s and 140s” (see Section 5.2.4.5 of this User Guide)
- “Waterway closures in either District” (see Section 5.3.2.1 of this User Guide)

6.2 Known Issues

The DOMICE Simulation model represents a significant increase in the capability, reliability, rigor, and accuracy of the current DOMICE model. The update to version 2.0 of the model added additional features and addressed a number of outstanding concerns. However, like all models, it remains an imperfect reflection of reality. In particular, limitations in data availability led to several modeling decisions that reduced the overall quantitative accuracy of the simulation model. While there are innumerable areas where this, like any model, could be improved, several key areas are highlighted here for future enhancements.

District 1 Ice Conditions Prediction. Ice conditions for District 1 are generated based on a regression model that attempts to predict ice conditions based on air temperature. The regression model was created based on the relationships between air temperature and ice conditions that exist in District 9. The existing regression model has a low level of accuracy (low R^2 scores), which contributes to model uncertainty surrounding the District 1 ice conditions. Additionally, using District 9 as a baseline assumes the relationship between weather and conditions is the same in District 1; due to differences in salinity, tides, and vessel traffic that may not be true. While this approach provides a reasonable approximation of ice conditions, it may misstate the absolute level of ice in District 1, and thus inaccurately predict the absolute level of risk. Ideally this process can be improved by following the approach in District 9 and directly collecting the ice thickness data in District 1. This would require working with the NOAA National Ice Center to begin gathering this data; this may be constrained by the available satellite information. Alternatively, gathering a small subset of ice direct ice data from District 1, along with other possible independent variables, could be used to build a more robust regression model.

Economic Impact Modeling. The economic impact models are built around general expected impacts for types of cargo and the general type of impact to the wider economy. This is particularly pertinent in the case of impacts to downstream consumers of delayed goods. This general approach to downstream economic impacts treats all delays of a certain quantity of goods as economically equivalent, which is unlikely to mirror the reality of the supply chains in the specific Districts. Conversion to a daily time step reduced some inaccuracy around the economic modeling, though issues still remain. While the relative

levels of economic impacts are consistent, the absolute level of economic impact may be inaccurate. Additional modeling and research could develop more robust models of the supply chains for taconite, steel, and coal in District 9 and home heating oil in District 1.

7 DATA ANALYSIS AND STORAGE

7.1 Overview of Data Analysis and Storage

The DOMICE model requires extensive data inputs ranging from SME description of icebreaking policies to the costs to ship home heating oil. While many of these data sources are recommend for annual updating, three particular data sources are highlighted here. All three data sources require substantial processing and analysis time; therefore, automated processes and computational scripts were created to expedite and standardize the process for future model updates.

This section describes the types of raw data and reviews the process for generating updated inputs for the Analytica® model. The three data sources and processes addressed are:

- 1) Automatic Identification System (AIS) data, indicating vessel traffic on all Tier 1 and Tier 2 waterways within District 1 and 9;
- 2) Ice data, demonstrating the severity of ice conditions found on critical waterways in District 9; and
- 3) Meteorological data, used to estimate ice conditions in District 1.

There are four major steps involved in processing and formatting the raw data to obtain final outputs. These steps include:

- 1) Database setup;
- 2) Data input and scrub;
- 3) Running processing scripts; and
- 4) Formatting the data output to be compatible with the software package Analytica® that was used to develop the model.

The following sub-section will present general system requirements that must be met prior to data processing. Section 6.3 will describe the configuration of the data files to ensure that all the necessary files can be readily located. The remainder of Section 6 will describe the methodology for obtaining and processing data for each of the three types of data. For each data type, the four major steps for data processing and formatting will be discussed in detail.

7.2 General System Requirements

Several system requirements must be met in order to run the data processing scripts successfully. These requirements include: sufficient computing power; a PHP/MySQL environment; and access to Port 80/Webserver.

7.2.1 Sufficient Computing Power

A large amount of computing power is necessary to run the scripts in a reasonable timeframe. The following minimum system requirements are recommended to ensure that any given run takes no more than a day or two:

- A Quad core 2.4 GhZ processor;
- 8 GB RAM; and
- 120 GB SSD.

7.2.2 PHP / MySQL Environment

The scripts have been designed to run from within a PHP/MySQL development environment, commonly called a LAMPP or XAMPP environment. A PHP/MySQL environment consists of a computer configured to act as a server with PHP scripting language and the MySQL database installed and running. A single file can be downloaded and installed that will set up the entire environment. This file can be downloaded from the following website: www.apachefriends.org.

The database must be set up in order to allow the user to read, write, and perform arithmetic and sorting functions within the tables. The credentials for that user should be stored in plain text in the “config.php” files for the scripts.

7.2.3 Access to Port 80 / Webserver

The scripts are written in PHP scripting language and are designed to work best when run from a web browser and displayed over a HTTP connection. A HTTP connection provides the user with information on the progress of running the scripts, as well as properly formatting the output from the database to be compatible with the *Analytica*® software. While the scripts can run from the command line, their outputs are not designed for that format.

7.3 Data Configuration

This section outlines the location and organization of the data files needed to perform the data updates.

The “Data” folder contains the following subfolders:

- “ACCESS DATABASE,” which contains the following files referenced in this document:
 - “DOMICE_CB.2011.09.16.accdb” (Note: The “Query1” file is located in this database.)
 - “Query2.xlsx”
- “Waterway Maps,” which contains the following file reference in this document:
 - “waterways_v5.kml,” which is the Google Earth KML file that demonstrates the AIS data “boxes” and central GPS points used.

- “Weather,” which contains the following file referenced in this document:
 - “Waterways20120120.xlsx,” which is the Microsoft Excel document that indicates all the waterways and waterway systems considered in District 1 and District 9.

The “Data” Folder also contains the following files, saved in the main folder location:

- “boxmap.htm,” which is the map of the grid system used to characterize the ice severity in the Great Lakes region.

The following files are necessary for processing the three types of raw data:

- For AIS data processing, the following scripts are used:
 - The scrubbing script “scrub.php”
 - The processing script “wwmonthly.php”
 - The output formatting script “AISoutput.php”
- For ice severity data processing for District 9, the following scripts are used:
 - The script “phase1.php,” that replaces the SIGRID ice codes with a new code indicating whether the ice is loose brash, packed brash, or plate ice.
 - The script “phase2.php” that inputs the data from the “temp1” table.
 - The output formatting script “iceoutput.php”
- For meteorological data processing for District 1, the following scripts are used:
 - The “scrub.php” script
 - The script “scrub2.php,” used for parsing data obtained from the Wunderground website into a format identical to that used for the NOAA data.
 - The processing script “phase1.php” for the raw meteorological data
 - The output formatting script “weatheroutput.php”
- Before proceeding to run any scripts, the credentials for the MySQL server must be properly stored in all “config.php” files. Each folder in the scripts directory has its own “config.php” file to enable separate databases for each data type.

The following three databases must be created to input and process raw data:

- The “ais” database
- The “ice.sql” database
- The “weather” database

The default credentials for the database include the following passwords for the current server, presented as [username/password]:

- HTTP Password: [luser\wallstreet]
- MySQL Password: [root\wallstreet]
- FTP Password: [luser\wallstreet]

7.4 AIS Data Processing

7.4.1 Overview of AIS Data

AIS data allows the DOMICE model to account for variations in vessel traffic and commodity flow in order to determine a range in possible demand for icebreaking resources. AIS data consists of daily vessel records for each district in a given year.

In order to match the position of each vessel record to a critical waterway, every Tier 1 and Tier 2 waterway in District 1 and 9 are assigned two numbers in the database. The first number is the GPS coordinate of a point within the waterway that ships are most likely to pass through. These points were determined after identifying shipping lanes and major channels in each waterway from USCG navigational charts. Each GPS point was then refined to ensure that all possible shipping lanes would be encompassed by a geographical “box” drawn around the designated central point. The second number identifies the distance, in degrees, of the edges of this “box” from the central GPS point. These two numbers together define a set of geographical “boxes” for all waterways within the scope of the project.

The processing scripts are designed to utilize AIS data to locate and count every vessel that appears in each “box” per day. This count is done by mathematically comparing the latitude and longitude of the location of every vessel reported in the dataset to the central GPS point of each waterway and determining whether the difference between the two sets of coordinates are within the limits of the areas designated by the “boxes.” For example, if a vessel is located at a longitude of -75.825 and the central GPS point on the St. Lawrence Seaway is located at a longitude of -75.718 with the edges of its “box” being 0.4 degrees on either side of this point, then the vessel would be considered located in the Seaway, provided that the vessel’s latitude is also within the given area.⁷

Designating a single GPS location for a waterway and defining a geographical box encompassing that point allows the location of vessels to be determined without mapping individual vessel locations. The number of unique vessels identified per day within each designated area is tallied by vessel type. The GPS points and associated boxes for each waterway can be found in a Google Earth KML file named “waterways_v5.kml,” located in the “Waterway Maps” subfolder of the “Data” folder. Figure 52 in Section 7.4.2 demonstrates a sample from the Google Earth file.

⁷ Specifically, the following calculation would be performed for this example: $([-75.718] - [-75.825]) = 0.107$. Since 0.107 is less than 0.4, the vessel’s longitude is within the “box” associated with the St. Lawrence Seaway. The vessel’s latitude would be calculated similarly. If both vessel coordinates are found to be within the limits of the “box,” the vessel would be counted as transiting the St. Lawrence Seaway on that particular day.

7.4.2 Obtaining AIS Data

AIS data for the project was obtained from the USCG Navigation Center (NavCenter). Data requests for the NavCenter can be submitted online through the NavCenter's historical data request web portal at <http://www.navcen.uscg.gov/?pageName=dataRequest&dataRequest=aisHistoricalRequestForm>.

An abridged copy of the request submitted to the NavCenter containing the appropriate technical details is shown below.

9. Intended Use Of NAIS Data: The USCG Research and Development Center is developing a decision support tool for domestic ice breaking resource allocation as part of Atlantic Area's Operational Risk Assessment Model (ORAM). In support of this effort, a task order was issued to ABS Consulting to prepare a risk based model which will more accurately describe the economic impact of ice breaking in the Great Lakes and on the East Coast. The use of National AIS Data would allow those analysts to determine the value of goods flowing per day per waterway in the Great Lakes and East Coast by accurately identifying the historical volume of traffic for that waterway. The impact of Coast Guard icebreaking resource decisions on traffic flow based on historic cargo traffic and ice conditions will provide the basis for the decision support tool.

The risk tool will support decisions relating to icebreaker assignments between D1 and D9. In order to capture traffic in both of those areas, two request are being submitted, one for each District.

Data is only requested for the "ice season" (December 11 through April 30) of each year. Data as far back as is available is requested, recognizing that NAIS data is not available as far back as the full study period (1998-2011).

10. Period of Interest - From: 12/11/1998

11. Period of Interest - To: 04/30/2011

12. Time Frame: Start Time: 0001Z End Time: 2359Z

...

14. For LE or Legal Action: No

...

16. Area of Interest:

Degrees, minutes, seconds

Upper Right Latitude: 49 01 51 N

Upper Right Longitude: 75 35 4 W

Lower Left Latitude: 41 17 10 N

Lower Left Longitude: 92 13 10 W

...

18. Requested Data Formats: Comma Delimited Format (.CSV)

19. Sample Rate Requested: 5 minutes aggregate

20. Additional Comments: Data only needed for winter navigation season (December 11 through April 30) for each year. We understand NAIS data does not extend back to 1998 but request earliest available data.

Message IDs:

Message IDs 1, 2, 3, 5, 11, 18, 19, and 24 were requested.

The same request was submitted for District 1, defining the area of interest as a polygon based on the following geographic coordinates:

(45°30'0"N 67° 0'0"W), (44°0'0"N 67° 0'0"W), (43°0'0"N 69° 0'0"W), (41°0'0"N 69° 0'0"W), (40°0'0"N 74° 0'0"W), (41°30'0"N 74° 30'0"W)



Figure 53. Sample file indicating the central GPS points and surrounding geographical “boxes” for critical waterways.

Data from AIS traffic is added to the Analytica® model in four variables:

- D1 Vessels Per Historical Year (D1_vessels_per_histo)
- D9 Vessels Per Historical Year (D9_vessels_per_histo)
- Ice Season Waterway Traffic (Ais_w_d2)
- Ice Season Waterway Traffic (Ais_w_is9)

Details on updating these variables are included in Section 4 of this User Guide.

7.4.3 Step 1: Database Setup

Of the three main data types, AIS data requires the most time to compile and run. Before AIS data can be processed, the following seven tables must be created in a database titled “ais.” All table names must be in lower case letters. Columns found within each table are presented in the format “Name [type, length].” All column names are case sensitive. All data types are MySQL standard types.

- 1) “Analytica®”- This table is used to format the output properly for use with *Analytica*® software. The table has two columns:
 - Name [text]
 - ID [int,10]
- 2) “data” – The raw data is input and stored in this table before it is scrubbed. The table contains the following columns:

- MMSI [int,20]
- IMO [int, 20]
- CALL [varchar, 20]
- NAME [varchar, 100]
- COUNTRY [varchar, 10]
- TIME [varchar, 20]
- LAT [varchar, 20]
- LONG [varchar, 20]
- SPEED [varchar, 30]
- HEADING [varchar, 20]
- COG_DEG [varchar, 30]
- NAV [int, 10]
- ROT_DEG [varchar, 10]
- IMO2 [int, 20]
- CALL2 [varchar, 30]
- TYPE [int, 20]
- NAV2 [int, 10]
- ETA [int, 20]
- DRAUGHT [varchar, 30]
- DESTINATION [varchar, 100]

3) “result” – The results of the scripts are stored in this table. The table contains the following columns:

- Year [int, 20]
- Month [int, 20]
- DAY [int, 3]
- Waterway [int, 20]
- Total [int, 100]
- Passenger [int, 20]
- Cargo [int, 20]
- Tanker [int, 20]

4) “scrubbed” – The data is stored in this table once it is scrubbed from the “data” table. Here, it is readied for processing. The “time” has been split into the year, month, and day. Most of the extraneous data has been removed. The table includes the following columns:

- MMSI [int,20]
- IMO [int, 20]
- CALL [varchar, 20]
- NAME [varchar, 100]
- COUNTRY [varchar, 10]
- YEAR [int, 5]
- MONTH [int, 4]
- DAY [int, 4]
- LAT [varchar, 20]
- LONG [varchar, 20]



- TYPE [int, 20]
 - ETA [int, 20]
 - DRAUGHT [varchar, 30]
 - DESTINATION [varchar, 100]
- 5) “temp” – This is a temporary table used during processing. No data should be in this table unless a script is running. Only data that the script places in the table should be allowed to remain. This table has the following columns:
- MMSI [int, 30]
 - Waterway [int, 10]
 - DATE [int, 20]
 - TYPE [int, 30]
- 6) “temp_b” – This is another temporary table. Again, the only data in this table should be data placed there by scripts. Its columns include:
- Year [int,20]
 - Month [int,20]
 - DAY [int,3]
 - Waterway [int,20]
 - Total [int,100]
 - Passenger [int,20]
 - Cargo [int,20]
 - Tanker [int,20]
- 7) “waterway” – This table is designed to act as a reference for every waterway in the model and defines each waterway’s respective AIS “box.” Latitude and longitude are stored as strings and converted to numbers in the script. This table consists of the following columns:
- Waterway_ID [int, 10]
 - Waterway_Name [text]
 - MP_Lat [varchar, 100]
 - MP_Long [varchar, 100]
 - CheckRadius [double, 4,4]
 - Criticality [int, 10]
 - Area [int, 10]
 - OOS [int, 3]

The “Analytica®” and “waterway” tables should have the data pre-populated before the import procedure begins.

7.4.4 Step 2: Input and Scrub

The USCG provided AIS data for all vessel traffic in the identified areas of Districts 1 and 9. The AIS data incorporated into the DOMICE model includes a variety of data types, each represented by one of the following message IDs used by USCG:

- Message ID 1, or scheduled position reports for Class A ship borne mobile equipment;
- Message ID 2, or assigned scheduled position reports for Class A ship borne mobile equipment;
- Message ID 3, or special position reports and responses to interrogation for Class A ship borne mobile equipment;
- Message ID 5, or scheduled static and voyage-related vessel data reports for Class A ship borne mobile equipment;
- Message ID 11, or current Coordinated Universal Time (UTC) and date;
- Message ID 18, or standard position reports for Class B ship borne mobile equipment;
- Message ID 19, or extended position reports for Class B ship borne mobile equipment; and
- Message ID 24, or additional static data assigned to an MMSI.

MMSI,IMO_NUMBER,CALL_SIGN,NAME,MMSI_COUNTRY_CD,PERIOD,LAT_AVG,LON_AVG,SPEED_KNOTS,HEADING_DEG,COG_DEG,NAV_STATUS,ROT_DEG,IMO_NUMBER,CALL_SIGN,SHIP_AND_CARGO_TYPE,NAV_SENSOR,ETA,DRAUGHT,DESTINATION

366904940,7729057,WYR4481,PAUL R.TREGURTHA,US,2008-12-11 00:00:00,43.597626,-82.490144,12.4,352,352.6,0,0,7729057,WYR4481,70,1,10102300,7.0,SUPERIOR

366905890,7390260,WYP8657,JAMES R BARKER,US,2008-12-11 00:00:00,43.017401,-82.416198,9.7,180,180.4,0,9,7390260,WYP8657,70,1,10110846,8.1,A

The data is provided from the NavCenter in CSV format, which the MySQL database will recognize and sort into the appropriate columns. The following data rows from District 9 on December 11, 2008 provide an example of the data format. Only the first three data rows are shown here:

Data provided by the USCG should import into the “data” table in the database without difficulty, after removing the first row of data that provides the header information. It should be noted that if this first row of data is not removed prior to data import, the import will proceed normally but some functions in the script will later fail when they are unable to parse the information.

Before proceeding to run any scripts, the credentials for the MySQL server must be properly stored in all “config.php” files. Each folder in the scripts directory has its own “config.php” file to enable separate databases for each data type. Each “config.php” must be individually edited.

Once the data is imported into the database, the scrubbing script can be run. This script can be found in the “scrub.php” file. The scrubbing script will parse the data from the “data” table into the “scrubbed” table 30,000 rows at a time. It is not recommended to scrub more than 30,000 rows at a time because the script will take too long and use too much memory. It is highly recommended that only a single year of AIS data from a single region be run at once. Smaller subsets of the data are easier to work with, will allow errors to be identified faster, and will keep the processing requirements for the data relatively low.

Once the scrubbing is complete, the result should be a table with all of the AIS data for a given year within a given district. In order for this data to be utilized in the DOMICE model, the location of each vessel report must be compared to the geographical “boxes” characterizing the critical waterways.

The processing script “wwmonthly.php” performs the following tasks in sequence repeatedly for each day and waterway within the 20-week winter navigation season:

The data in the “result” table must be formatted so that the data output is aligned with the expected input for the *Analytica*® software. The output formatting script is named “AISoutput.php” and should be run from a web browser for best results.

The standard output in the database prior to running the script can be seen in the following sample data set from December 10, 2008:

7.4.5 Step 3: Run Processing Scripts

- 1) The script identifies all of the vessel records for a given day and places these records into a temporary table. This step accelerates the runtime by reducing the number of records to be analyzed.
- 2) For each vessel record in the temporary table, the script examines whether it falls within the designated geographical “box” of each waterway. If the vessel record matches with a “box,” the record is placed into a second table. Records that are not matched to any of the waterways’ “boxes” are not added to this secondary table and, instead, are discarded.
- 3) Once all of the vessel records have been processed, the computer tallies the number of unique vessels identified within a “box” for a given day and categorizes the total number of vessels by vessel type. This action is performed by checking the table for unique Maritime Mobile Service Identities (MMSIs), which are nine digit numbers used to uniquely identify a ship. The total count of unique entries found is recorded. This process ensures that any vessel will be counted only once per day, despite the number of times in a given day that it may transit the waterway.
- 4) The type of each vessel is assigned based on the self-reported status on vessel type found in the AIS message.
- 5) The results of the vessel count are recorded in the “result” table.

7.4.6 Step 4: Format Output for *Analytica*®

"Year", "Month", "DAY", "Waterway", "Total", "Passenger", "Cargo", "Tanker"

"2008", "12", "10", "20", "0", "0", "0", "0"

"2008", "12", "10", "21", "0", "0", "0", "0"

"2008", "12", "10", "22", "0", "0", "0", "0"

"2008", "12", "10", "23", "0", "0", "0", "0"

The formatted output after running the script is displayed in terms of the total number of unique vessels found to be transiting a waterway from week 1 to week 20 of the winter navigation season. A sample is provided here of the formatted output for Black Rock Harbor in 2009-2010:

Season 2, years 2009-2010

Waterway	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Black Rock Harbor	60	48	66	74	68	76	72	92	66	76	56	84	70	64	60	60	56	66	62	36

Data from AIS traffic is added to the Analytica® model in four variables:

- D1 Vessels Per Historical Year (D1_vessels_per_histo)
- D9 Vessels Per Historical Year (D9_vessels_per_histo)
- Ice Season Waterway Traffic (Ais_w_d2)
- Ice Season Waterway Traffic (Ais_w_is9)

The output format is designed to allow for copying data directly from the output tables and pasting into the appropriate variables in *Analytica*®. Details on updating these variables are included in Section 4 of this User Guide.

7.5 Ice Data Processing

7.5.1 Overview of Ice Data

The DOMICE model utilizes historical ice severity data in District 9 to account for the impact of ice conditions on the demand for icebreaking resources. The NOAA National Ice Center (NIC) generates weekly or semi-weekly ice reports for the Great Lakes. This data is exported into GIS shape files that use discrete GPS coordinates to define the geometric “shape” of the ice cover in the Great Lakes. For each shape file in the ice reports, there is an associated list of attributes to characterize the ice within the outlined area. These attributes are provided in terms of ice codes recorded as Sea Ice Grid (SIGRID) code values established by the World Meteorological Organization (WMO). The following four types of attributes were provided to assess the ice severity on the Great Lakes: total concentration (CT); partial concentration of thickest ice (CA); stage of development of thickest ice (SA); and form of thickest ice (FA). The ice severity data is reported in a database.

Because absolute conditions and regular points are not used to define the ice cover shapes, the shape files are not easily read by a database. In order to relate the data associated with the ice cover shape files to a database format, a grid system consisting of 25 square kilometer boxes was developed to cover the surface area of the Great Lakes. The entire grid spans an area 258 kilometers wide and 174 kilometers long, covering a total of 44,892 square kilometers in the region. Of the total grid, only the 25 square kilometer boxes that included water bodies were reported in the database. The map of the grid system is available in the file named “boxmap.htm,” found in the “Data\Ice Map Code\IceMap Output” folder. A screenshot of a section of this grid can be seen in Figure 53. The blue highlighting indicates the 25 square kilometer boxes in the region that represent water bodies.

17367	17368	17369	17370	17371	17372	17373	17374	17375	17376	17377	17378	17379	17380	17381	17382	17383	17384	17385	17386	17387	17388	17389	17390	17391	17392	17393	17394
17625	17626	17627	17628	17629	17630	17631	17632	17633	17634	17635	17636	17637	17638	17639	17640	17641	17642	17643	17644	17645	17646	17647	17648	17649	17650	17651	17652
17883	17884	17885	17886	17887	17888	17889	17890	17891	17892	17893	17894	17895	17896	17897	17898	17899	17900	17901	17902	17903	17904	17905	17906	17907	17908	17909	17910
18141	18142	18143	18144	18145	18146	18147	18148	18149	18150	18151	18152	18153	18154	18155	18156	18157	18158	18159	18160	18161	18162	18163	18164	18165	18166	18167	18168
18399	18400	18401	18402	18403	18404	18405	18406	18407	18408	18409	18410	18411	18412	18413	18414	18415	18416	18417	18418	18419	18420	18421	18422	18423	18424	18425	18426
18657	18658	18659	18660	18661	18662	18663	18664	18665	18666	18667	18668	18669	18670	18671	18672	18673	18674	18675	18676	18677	18678	18679	18680	18681	18682	18683	18684
18915	18916	18917	18918	18919	18920	18921	18922	18923	18924	18925	18926	18927	18928	18929	18930	18931	18932	18933	18934	18935	18936	18937	18938	18939	18940	18941	18942
19173	19174	19175	19176	19177	19178	19179	19180	19181	19182	19183	19184	19185	19186	19187	19188	19189	19190	19191	19192	19193	19194	19195	19196	19197	19198	19199	19200
19431	19432	19433	19434	19435	19436	19437	19438	19439	19440	19441	19442	19443	19444	19445	19446	19447	19448	19449	19450	19451	19452	19453	19454	19455	19456	19457	19458
19689	19690	19691	19692	19693	19694	19695	19696	19697	19698	19699	19700	19701	19702	19703	19704	19705	19706	19707	19708	19709	19710	19711	19712	19713	19714	19715	19716
19947	19948	19949	19950	19951	19952	19953	19954	19955	19956	19957	19958	19959	19960	19961	19962	19963	19964	19965	19966	19967	19968	19969	19970	19971	19972	19973	19974
20205	20206	20207	20208	20209	20210	20211	20212	20213	20214	20215	20216	20217	20218	20219	20220	20221	20222	20223	20224	20225	20226	20227	20228	20229	20230	20231	20232
20463	20464	20465	20466	20467	20468	20469	20470	20471	20472	20473	20474	20475	20476	20477	20478	20479	20480	20481	20482	20483	20484	20485	20486	20487	20488	20489	20490
20721	20722	20723	20724	20725	20726	20727	20728	20729	20730	20731	20732	20733	20734	20735	20736	20737	20738	20739	20740	20741	20742	20743	20744	20745	20746	20747	20748
20979	20980	20981	20982	20983	20984	20985	20986	20987	20988	20989	20990	20991	20992	20993	20994	20995	20996	20997	20998	20999	21000	21001	21002	21003	21004	21005	21006
21237	21238	21239	21240	21241	21242	21243	21244	21245	21246	21247	21248	21249	21250	21251	21252	21253	21254	21255	21256	21257	21258	21259	21260	21261	21262	21263	21264
21495	21496	21497	21498	21499	21500	21501	21502	21503	21504	21505	21506	21507	21508	21509	21510	21511	21512	21513	21514	21515	21516	21517	21518	21519	21520	21521	21522
21753	21754	21755	21756	21757	21758	21759	21760	21761	21762	21763	21764	21765	21766	21767	21768	21769	21770	21771	21772	21773	21774	21775	21776	21777	21778	21779	21780
22011	22012	22013	22014	22015	22016	22017	22018	22019	22020	22021	22022	22023	22024	22025	22026	22027	22028	22029	22030	22031	22032	22033	22034	22035	22036	22037	22038
22269	22270	22271	22272	22273	22274	22275	22276	22277	22278	22279	22280	22281	22282	22283	22284	22285	22286	22287	22288	22289	22290	22291	22292	22293	22294	22295	22296
22527	22528	22529	22530	22531	22532	22533	22534	22535	22536	22537	22538	22539	22540	22541	22542	22543	22544	22545	22546	22547	22548	22549	22550	22551	22552	22553	22554
22785	22786	22787	22788	22789	22790	22791	22792	22793	22794	22795	22796	22797	22798	22799	22800	22801	22802	22803	22804	22805	22806	22807	22808	22809	22810	22811	22812
23043	23044	23045	23046	23047	23048	23049	23050	23051	23052	23053	23054	23055	23056	23057	23058	23059	23060	23061	23062	23063	23064	23065	23066	23067	23068	23069	23070
23301	23302	23303	23304	23305	23306	23307	23308	23309	23310	23311	23312	23313	23314	23315	23316	23317	23318	23319	23320	23321	23322	23323	23324	23325	23326	23327	23328
23559	23560	23561	23562	23563	23564	23565	23566	23567	23568	23569	23570	23571	23572	23573	23574	23575	23576	23577	23578	23579	23580	23581	23582	23583	23584	23585	23586
23817	23818	23819	23820	23821	23822	23823	23824	23825	23826	23827	23828	23829	23830	23831	23832	23833	23834	23835	23836	23837	23838	23839	23840	23841	23842	23843	23844
24075	24076	24077	24078	24079	24080	24081	24082	24083	24084	24085	24086	24087	24088	24089	24090	24091	24092	24093	24094	24095	24096	24097	24098	24099	24100	24101	24102
24333	24334	24335	24336	24337	24338	24339	24340	24341	24342	24343	24344	24345	24346	24347	24348	24349	24350	24351	24352	24353	24354	24355	24356	24357	24358	24359	24360

Figure 54. Screen snapshot of a portion of the Great Lakes waterway grid system, located in the “boxmap.htm” file.

Each Tier 1 and Tier 2 waterway in District 9 was aligned with its corresponding 25 square kilometer boxes in the grid system. This alignment was done manually, comparing the geographic location of each waterway to the grid. The SIGRID ice codes were then used to re-code the ice severity levels for each 25 kilometer box of a waterway in terms of one of the following three types of ice: loose brash; packed brash; or plate ice. By considering the type of ice characterizing each of the boxes of a waterway, the overall ice severity conditions of the waterway could be determined. For several waterway systems, like the Sault St. Marie Waterway System, several of the individual waterways within the larger waterway system were too narrow to assess ice severity using the ice cover shape file. In each of these cases, however, there was enough data for other larger waterway segments within the waterway system to categorize the ice severity of the waterway system as a whole. The Microsoft Excel document “Waterways20120120.xlsx,” located in the “Weather” subfolder of the “Data” folder, provides a list of all the waterways and waterway systems included in the analysis.

7.5.2 Obtaining Ice Data

Ice severity data for District 9 is compiled continuously, with approximately a one-week lag between data collection and data reporting. Ice data for District 9 should be conducted approximately one month after the end of each winter navigation season. The NIC is in the process of providing the standard reports through their website at http://www.natice.noaa.gov/products/great_lakes.html. For questions regarding NIC support, contact:



Caryn Panowicz
Operations Technical Advisor
National Ice Center
NOAA/NESDIS
Suitland, MD
caryn.panowicz@noaa.gov
(301)817-3942

7.5.3 Step 1: Database Setup

Of the three types of data used in the DOMICE model, the ice data for District 9 is the easiest to process. No scrubbing of the data is necessary in order to setup the database. Before the ice data can be processed, the following six tables must be created in a database titled “ice.sql.”

- 1) “data” – The raw ice data is stored in this table. The table contains the following columns:
 - PKEY [int, 100, KEY]
 - Waterway_ID [int, 10]
 - Waterway_Name [text]
 - DAY [int, 10]
 - CT [int, 10]
 - CA [int, 10]
 - SA [int, 10]
 - FA [int, 10]
- 2) “result” – This table stores the results and contains the following columns:
 - Waterway_ID [int, 10]
 - Season [int, 20]
 - WEEK [varchar, 20]
 - YEAR_ID [int, 20]
 - A [int, 10]
 - B [int, 10]
 - C [int, 10]
- 3) “temp1” – This table is one of the tables used to temporarily hold ice data. It contains the following columns:
 - PKEY [int, 100, KEY]
 - Waterway_ID [int, 10]
 - Waterway_Name [text]
 - Y [int, 20]
 - M [int, 20]
 - D [int, 20]

- CT [int, 10]
 - CA [int, 10]
 - SA [int, 10]
 - FA [int, 10]
- 4) “temp2” – This table is another temporary data table. It contains the following columns:
- PKEY [int, 100, KEY]
 - Waterway_ID [int, 10]
 - Waterway_Name [text]
 - Y [int, 20]
 - W [int, 20]
 - CT [int, 10]
 - CA [int, 10]
 - SA [int, 10]
 - FA [int, 10]
- 5) “Waterway” – This table is used to identify waterway names and locations. The following columns are included in the table:
- Waterway_ID [int, 10]
 - Waterway_Name [text]
 - MP_Lat [varchar, 100]
 - MP_Long [varchar, 100]
 - CheckRadius [double, 4,4]
 - Criticality [int, 10]
 - Area [int, 10]
 - OOS [int, 3]
- 6) “wtemp” – This temporary table contains the following columns:
- WW [int, 20]
 - W [int, 5]
 - CT [int, 10]
 - CA [int, 10]
 - SA [int, 10]
 - FA [int, 10]

7.5.4 Step 2: Input and Scrub

Data from the NOAA Ice Center is provided in a slightly different format than that used in the MySQL database. An Access database entitled “DOMICE_DB.2011.09.16.accdb,” located in the “ACCESS DATABASE” subfolder of the “Data” folder, contains both the ice data and the data relating each waterway

to its respective 25 square kilometer boxes on the grid. A query named “query1” is available in the “DOMICE_DB.2011.09.16.accdb” database to format the ice data to match the format of the “data” table in the MySQL database. The Access database provides the necessary relationship between the ice data and the waterways’ boxes for the query to match each row of new ice data with its appropriate waterway ID code. Waterway ID codes are used instead of waterway names for the ice data in the database, as the names will be deleted during the calculation process and added back in at the end.

7.5.5 Step 3: Run Processing Scripts

There are two processing scripts that must be run in series. The first script, “phase1.php,” converts the timestamp to a machine-readable version. It then replaces the one of the SIGRID ice codes, the FA code, with a new code indicating whether the ice formation in any 25 square kilometer box is considered loose brash, packed brash, or plate ice. This exchange of codes takes place through a large IF/ELSE function, in order to allow different definitions of ice types to be updated quickly, if necessary. The “phase1.php” script outputs data into the “temp1” table to be utilized in by the second script.

The second script, “phase2.php,” inputs the data from the “temp1” table and clears the data from the “wtemp,” “temp2,” and “result” tables. For each waterway, the script locates each of the 25 square kilometer boxes that contains a segment of the given waterway and gathers the ice severity data pertaining to each box for each week of the ice seasons in which data is available. This ice severity data is then placed into the “wtemp” table, where the worst ice conditions observed in a given waterway for that week are mathematically calculated. These calculated values are then stored in the “result” table for analysis.

7.5.6 Step 4: Format Output for *Analytica*®

The ice data in the “result” table must be formatted so that the data output is aligned with the expected input for the *Analytica*® software. The output formatting script is named “iceoutput.php” and should be run from a web browser for best results. The data will be formatted so that the user can perform a simple copy and paste function from the browser into a Microsoft Excel document, and then into the model in *Analytica*®.

Unformatted data output from the database will appear in the following format:

```
"Waterway_ID","Season","WEEK","YEAR_ID","1","2","3"
"1","1","1","1998","0","0","0"
"2","1","1","1998","0","0","0"
"3","1","1","1998","0","0","0"
```

After running the output formatting script, the data will be properly formatted to display one data table for each of the three ice types (namely, loose brash, packed brash, or plate ice) per year, with ice data for each of the 20 weeks of the winter navigation season. The final data format will appear as follows:

Season 1, years 1998-1999

Ice Type A

Waterway	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	0	0	0	87	85	99	87	85	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	85	85	85	87	0	0	0	99	87	87	87	0	0	0	0	0

DOMICE Simulation Model User Guide

Data on District 9 ice conditions is added to the Analytica® model for the variable “D9 Historical Ice Data (SIGRID Coded) NBL Waterways *” (D9_historical_ice_d3). The model will convert the SIGRID ice code values to feet of thickness using the variable ‘SIGRID code conversion to feet of ice thickness’ (Sigrid_code_conversi).

Results from the database are based on the waterway numbering scheme shown below.

Table 1. Database waterway numbering scheme.

Database Waterway ID	Waterway Name
1	St. Lawrence
2	Straits of Mackinac
3	Sault St. Marie Waterway System
4	Detroit River System
7	Pelee Passage
8	Saginaw Bay
9	Southern Lake Michigan
10	Grand Traverse Bay
11	Lake Ontario
12	Western Lake Superior
13	Thunder Bay
14	Eastern Lake Erie
15	Maumee Bay
16	Lower Green Bay
17	Upper Green Bay
19	Georgian Bay
20	Cape Cod Canal
22	Connecticut River
24	Kennebec River
25	Manhattan Waterway System
26	Hudson River Waterway System
27	Narragansett Bay Waterway System
28	Penobscot Bay
29	Penobscot River
31	Thames River
33	Newark Waterway System
34	New York Harbor
35	New Haven Harbor
36	Nantucket Waterway System
39	Boston Harbor
40	Piscataqua River
42	Stage Harbor
43	Town River
44	Black Rock Harbor
45	Port Jefferson
48	Vineyard Haven Harbor
49	Weymouth Black River
50	Weymouth Fore River



The output format is designed to allow for copying data directly from the output tables and pasting into the appropriate variables in *Analytica*®. Details on updating these variables are included in Section 4 of this User Guide.

In order to ensure the model runs accurately, District 1 weather data and District 9 ice data must both be updated in the model. Without providing data for both districts, the model will generate errors for the district without any updated data, and thus generate invalid results.

7.6 Meteorological Data Processing

7.6.1 Overview of Meteorological Data

The DOMICE model utilizes meteorological data to assess the impact of ice conditions in District 1 on the demand for icebreaking assets. Unlike District 9, there is no quantitative data currently available for District 1 that measures the ice severity on critical waterways in past winter navigation seasons. The only information available for ice conditions consists of USCG ice reports that, while useful in validating the model's results, are qualitative in nature and cannot be quantified in a meaningful way for input into the model. Because of these restrictions in data availability, historical meteorological data is used to estimate past ice conditions in District 1.

Some of the meteorological data used was provided by the National Oceanic and Atmospheric Administration (NOAA). These datasets were, however, incomplete. To supplement the NOAA data, weather data was also used from the website www.wunderground.com. Daily weather reports were used to determine the ice severity on each waterway for a given day. This estimation was performed by using a formula derived by comparing the meteorological data from District 9 to the ice conditions observed in District 9. The only metric utilized from the NOAA and Wunderground weather reports for estimating ice severity was the average (mean) daily temperature. It was determined, however, that it would be more efficient to import the entire dataset of complete meteorological data and to then eliminate unnecessary fields, rather than to input daily mean temperatures manually.

7.6.2 Obtaining Meteorological Data

NOAA data was taken from the National Data Buoy Center (<http://www.ndbc.noaa.gov/>), which contains meteorological reports from buoys and ground stations. Data was collected from individual stations historical data sets, which are provided on a yearly basis

(e.g., http://www.ndbc.noaa.gov/station_history.php?station=mnmm4).

To process the data from the Wunderground website, the waterways in District 1 were divided into six geographical areas. Table 1 lists all of the District 1 waterways considered in the analysis and the area to which each was designated. The code for the weather station used in each region is shown in parentheses.

Table 2. Critical waterways in District 1.

Region	Waterway ID	Waterway
Cape Cod U.S. Coast Guard Air Station (KFMH)	20	Cape Cod Canal Waterway System
	27	Narragansett Bay Waterway System
	42	Stage Harbor
Bar Harbor (KBHB)	24	Kennebec River
	28	Penobscot Bay
	29	Penobscot River
	40	Piscataqua River
	21	Portland Waterway System
Albany International (KALB)	26	Hudson River Waterway System
Logan International (KBOS)	39	Boston Harbor
	43	Town River
	49	Weymouth Back River
	50	Weymouth Fore River
Farmingdale (KFRG)	44	Black Rock Harbor
	22	Connecticut River
	34	Manhattan Waterway System
	35	New Haven Harbor
	34	New York Harbor
	33	Newark Waterway System
	45	Port Jefferson
	31	Thames River
Nantucket (KACK)	36	Nantucket Waterways System
	48	Vineyard Haven Harbor

A single weather station, which usually was an airport, was selected for each of the six areas. The meteorological data collected at each weather station and reported through www.wunderground.com were used to indicate the weather conditions for all waterways in the respective area.

7.6.3 Step 1: Database Setup

Before the meteorological data can be processed, the following 10 tables must be created in a database titled “weather.”⁸

- 1) “bouy1” – This table aligns the buoy names to their respective waterways. This table contains two columns:
 - Waterway_ID [int, 10]
 - Buoy [varchar, 10]
- 2) “data” – This table contains the scrubbed data ready for analysis. Any areas for which data is unavailable should be automatically marked “999.” This table includes the following columns:

⁸ Buoy, though spelled incorrectly, is the correct designation used in the database.

- Buoy [varchar, 20]
 - Year [int, 10]
 - Month [int, 10]
 - Day [int, 10]
 - Hour [int, 10]
 - Min [int, 10]
 - WDIR [int, 10]
 - WSPD [int, 10]
 - GST [int, 10]
 - WVHT [int, 10]
 - DPD [int, 10]
 - APD [int, 10]
 - MWD [int, 10]
 - PRES [int, 10]
 - ATMP [int, 10]
 - WTMP [int, 10]
 - DEWP [int, 10]
 - VIS [int, 10]
 - TIDE [int, 10]
- 3) “icedata” – This table should be updated to reflect the latest results from the ice data analysis conducted for District 9. This table allows the most recent ice results to be printed next to the weather results for easy comparison. This table contains the following columns:
- Waterway_ID [int, 10]
 - Season [int, 20]
 - WEEK [varchar, 20]
 - YEAR_ID [int, 20]
 - 1 [int, 10]
 - 2 [int, 10]
 - 3 [int, 20]
- 4) “import” – Comparable to the “data” table in the AIS database, this table is used to place the raw data from NOAA in order to be scrubbed for import. All rows should be tagged with the appropriate buoy name before being imported into the table. This table contains two columns:
- Buoy [text]
 - ImportText [text]
- 5) “import2” – This table performs a similar function to that of the “import” table above. Instead of storing NOAA data, however, the “import2” table will be used to store the CSV output data from www.wunderground.com. The “Waterway_ID” must be tagged before beginning the import process. Daily temperatures are presented as maximum (abbreviated “Ma”), mean (abbreviated as “Me”), and minimum (abbreviated “Mi”) values. This table contains the following columns:
- Waterway_ID [int, 10]
 - Date [text]



- Ma_Temp [int, 10]
- Me_Temp [int, 10]
- Mi_Temp [int, 10]
- Ma_Dew [int, 10]
- Me_Dew [int, 10]
- Mi_Dew [int, 10]
- Ma_Humid [int, 10]
- Me_Humid [int, 10]
- Mi_Humid [int, 10]
- Ma_Pressure [int, 10]
- Me_Pressure [int, 10]
- Mi_Pressure [int, 10]
- Ma_Vis [int, 10]
- Me_Vis [int, 10]
- Mi_Vis [int, 10]
- Ma_Wind [int, 10]
- Me_Wind [int, 10]
- Mi_Wind [int, 10]
- Precip [int, 10]
- Cloud [int, 10]
- Events [text]
- WDir [int, 10]

- 6) “result” – The finished runs are stored in this table. Results are reported as daily values, and the output script converts daily values into weekly reports. This table contains the following columns:

- Waterway_ID [int, 10]
- YEAR [int, 10]
- WEEK [int, 10]
- DOW [int, 4]
- Buoy [varchar, 20]
- awspd [int, 10]
- mwspd [int, 10]
- aatmp [int, 10]
- FDD [int, 10]
- matmp [int, 10]
- awtmp [int, 10]
- mwtmp [int, 10]
- awvht [int, 10]
- mwvht [int, 10]
- adewp [int, 10]
- mdewp [int, 10]
- ICE1 [int, 10]
- ICE2 [int, 10]
- ICE3 [int, 10]



- 7) “temp” – This table is a temporary table used to hold data for processing while a script is running. This table should be empty before and after each run of the scripts. The table contains the following columns:
- bouy [varchar, 20]
 - Year [int, 10]
 - Month [int, 10]
 - Day [int, 10]
 - Hour [int, 10]
 - Min [int, 10]
 - WDIR [int, 10]
 - WSPD [int, 10]
 - GST [int, 10]
 - WVHT [int, 10]
 - DPD [int, 10]
 - APD [int, 10]
 - MWD [int, 10]
 - PRES [int, 10]
 - ATMP [int, 10]
 - WTMP [int, 10]
 - DEWP [int, 10]
 - VIS [int, 10]
 - TIDE [int, 10]
- 8) “temp1” – This is another temporary table. It should contain no data before or after scripts are run. Its columns include:
- Waterway_ID [int, 10]
 - buoy [varchar, 20]
 - awspd [int, 10]
 - mwspd [int, 10]
 - aatmp [int, 10]
 - matmp [int, 10]
 - awtmp [int, 10]
 - mwtmp [int, 10]
 - awvht [int, 10]
 - mwvht [int, 10]
 - adewp [int, 10]
 - mdewp [int, 10]
- 9) “Waterway” – This table is comparable to the “waterway” table in the AIS database. It is used primarily as a reference of waterway numbers and names. It contains the following columns:
- Waterway_ID [int, 10]
 - Waterway_Name [text]
 - MP_Lat [varchar, 100]



- MP_Long [varchar, 100]
- CheckRadius [double, 4,4]
- Criticality [int, 10]
- Area [int, 10]
- OOS [int, 3]

10) “weeks” – This table is used to check which days of the year pertain to each of the 20 weeks in the ice season. It contains three columns:

- week [int, 10]
- day [int, 10]
- month [int, 10]

The following tables should be populated prior to running the scripts: “bouy1,” “icedata,” “Waterway,” and “weeks.”

7.6.4 Step 2: Input and Scrub

The data import procedure for the “weather” database is slightly different than that of the AIS database. A main difference is that the data input procedure varies depending on whether the data is provided by NOAA or the Wunderground website.

7.6.4.1 Using Data Provided by NOAA

Data provided by NOAA should be input into the “import” table. Each row of data should be labeled with the appropriate buoy code and the data source (e.g., NOAA). It should be noted that row names are case sensitive, and it is recommended that all upper case letters be used.

Data from NOAA is provided in a tabbed format. The following sample data on March 10, 2009 from buoy 44020 provides an example of the format in which the NOAA data is originally presented:

```
2009 03 10 13 50 47 4.9 6.8 99.00 99.00 99.00 999 1028.4 3.1 3.2 -0.9 99.0 99.00
2009 03 10 14 50 59 3.8 4.7 99.00 99.00 99.00 999 1028.0 3.2 2.8 -0.5 99.0 99.00
2009 03 10 15 50 29 2.5 2.9 0.61 6.25 4.18 93 1028.6 3.2 2.9 0.4 99.0 99.00
```

The “scrub.php” script should be used to format the data properly. This script will deposit the properly formatted data in the “data” table. For the example data provided above, a properly tagged row would be in the following format:

```
44020,2009 03 10 17 50 67 3.0 3.5 99.00 99.00 99.00 999 1029.3 3.8 3.3 -0.4 99.0 99.00
```

7.6.4.2 Using Data Provided by Wunderground.com

Data provided by the Wunderground website will require a different table and a different script than the NOAA data. The data should be input into the “import2” table. Each temperature reading must be labeled with its corresponding waterway area code in the “Waterway_ID” column, in order to link the temperature data to a physical location. Unlike the NOAA data that provides temperature readings for a given buoy, the

Wunderground website provides temperature readings for a given weather station. Because one weather station provides temperature data for various waterways within its designated area, the same waterway area code will be repeated for all waterways within that area. The waterway area codes are as follows: 111 for Area 1; 222 for Area 2; 333 for Area 3; 444 for Area 4; 555 for Area 5; and 666 for Area 6.

The script “scrub2.php” should be used for the data obtained from the Wunderground website. Once the script has run, it will have parsed the data into a format identical to that used for the NOAA data. With the data from NOAA and Wunderground in the same format, the following steps can be carried out for both types of meteorological data.

7.6.5 Step 3: Run Processing Scripts

The processing script for the raw meteorological data is called “phase1.php.” This script places the raw data, which consists of daily temperature readings for each waterway in available years, into a temporary table named “temp” for faster processing. The script then calculates the mathematical average temperature and the maximum temperature values for each day. These results are recorded in the “results” table. The data in the “temp” table is then deleted in order to make the table available for use in subsequent runs.

7.6.6 Step 4: Format Output for *Analytica*®

The output formatting script is named “weatheroutput.php” and should be run from a web browser for best results. The user will be able to copy the displayed data output into a Microsoft Excel document and then into the DOMICE model in *Analytica*®.

The standard, unformatted output in the “weather” database is presented in the following format:

Waterway_ID, YEAR, WEEK, DOW, bouy, awspd, mwspd, aatmp, FDD, matmp, awtmp, mwtmp, awvht, mwvht, adewp, mdewp, ICE1, ICE2, ICE3

1, 1998, 1, 1, ALXN6,,,0,,0,,,,,0,0,0

1, 1998, 1, 1, OBG6,,,0,,0,,,,,0,0,0

Once the output formatting script has been run, the data will be properly formatted for compatibility with the *Analytica*® software. The data will be in the following format, displayed to indicate average temperature values for each of the 20 weeks in the winter navigation season:

Season 1, years 1998-1999

Waterway	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20	40	31	32	30	35	40	27	36	36	33	25	36	31	40	39	45	44	44	47	46
21	32	25	19	21	24	35	19	30	30	26	22	31	29	35	37	40	43	40	44	48

Data on District 1 air temperature is added to the *Analytica*® model for the variable “Historical District 1 Weekly Air Temperature Data” (Historical_district). The model will convert the air temperatures into ice depth based on the regressions completed for this model. In order to update the regression model itself, data must also be added to the excel tool used to complete the regressions.

The output must be converted from the waterway ID scheme to the named waterways in *Analytica*® using the key shown below.

In order to ensure the model runs accurately, District 1 weather data and District 9 ice data must both be updated in the model. Without providing data for both districts, the model will generate errors for the district without any updated data, and thus generate invalid results.